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AFML-TR-77-13

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DEVELOPMENT OF AIR BONDED FOD RESISTANT METAL MATRIX FAN BLADES

HAMILTON STANDARD DIVISION
UNITED TECHNOLOGIES CORPORATION
WINDSOR LOCKS, CONNECTICUT 06096

FEBRUARY 1977

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TECHNICAL REPORT AFML-TR-77-13
FINAL REPORT FOR PERIOD JUNE 1975 - JULY 1976

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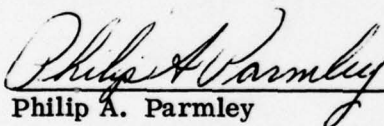
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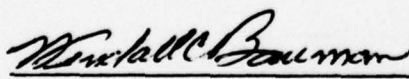
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19 REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFML-TR-77-13	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Development of Air Bonded FOD Resistant Metal Matrix Fan Blades.	5. TYPE OF REPORT & PERIOD COVERED Final Technical Report. June 1975 - July 1976.	
7. AUTHOR(s) E. J. Delgrosso W. J. Fisher	8. CONTRACT OR GRANT NUMBER(s) F33615-75-C-5285	9. PERFORMING ORGANIZATION REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hamilton Standard Division United Technologies Corporation Windsor Locks, Connecticut 06096	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 6-2102F Project 73510730	11. REPORT DATE March 1977
11. CONTROLLING OFFICE NAME AND ADDRESS Advanced Development Division Air Force Materials Laboratory Air Force Systems Company Wright Patterson AFB, Ohio 45433	12. NUMBER OF PAGES 154	13. SECURITY CLASS. (of this report) Unclassified
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Eugene J./Delgrosso, William J./Fisher, Karl M./Prewo Richard D./Veltri	15. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) NOTICE (Continued) Approved for public release, distribution unlimited. 12 162 p.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) N/A		
18. SUPPLEMENTARY NOTES N/A		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Advanced Composites, Fan Blades, Metal Matrix Composites, Low Cost Fabrication Techniques, Air Bonding, Quick Vacuum Bonding, Plasma Sprayed Tape, Aero-propulsion, Boron/Aluminum, Diffusion Bonding		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Advanced Composite aluminum matrix fan blades offer significant payoff to Air Force systems in terms of both cost saving and performance improvements. However, there are currently problems which must be overcome prior to the introduction of such blades to service. Two problem areas have been identified for solution before aluminum matrix composites can be applied to Air Force weapon systems - high cost and inadequate FOD resistance. Low cost bonding fabrication techniques have been identified, and feasibility demonstrated.		

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20. ABSTRACT (Continued)

Improved FOD resistance of boron aluminum composites has been explored on laboratory specimens and full size blades. This program will combine the previously identified solutions to FOD resistance with low cost bonding fabrication to provide a basis for validation of these technologies for future blade hardware. The fabrication approach will be air and "quick vac" bonding.

The program is organized in two tasks as follows:

I. Screening

A. General Evaluation

1. 8 and 5.6 Mil Boron
2. 1100 & 6061 Metal Matrix:
3. CMC & AVCO Fiber

B. Advanced Evaluation

1. 2 most promising systems from above
2. Fatigue, thermal cycle, rupture, impact tests to delineate best system.

II. Characterization

A. Best system from IB above

B. Properties reproducibility for uniaxial & blade orientations

FOREWORD

This Final Technical Report covers the work performed under Contract F33615-75-C-5285, from 20 June 1975 through 31 July 1976.

This contract, with Hamilton Standard Division of United Technologies Corporation Windsor Locks, Conn. 06096 was initiated under AF Advanced Development Project 69CW for the Development of Air Bonded FOD Resistant Metal Matrix Fan Blades. The work is administered under the technical direction of Mr. Philip A. Parmley, Advanced Development Division, Air Force Materials Laboratory, Wright Patterson Air Force Base, Ohio.

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This report was submitted by the authors in November, 1976.

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SECTION 1.0 INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

The purpose of this contract was to develop low cost air bonding processing techniques for boron aluminum, and demonstrate the applicability of this process in providing FOD resistant matrix composites. This was accomplished by specimen testing at RT and environmental conditions, with a final component fabrication demonstration.

The feasibility of air bonding boron aluminum was demonstrated by United Technologies Research Center under AF contract F33615-73-C-5152, using 5.6 mil boron. Hamilton Standard further developed this process through specimen testing and quick bonding in air F-100 vanes with both 5.6 and 8.0 mil boron with 6061 aluminum matrix. This in-house work was initiated prior to this contract, but continued to parallel the contract work by providing 8 mil fiber 6061 aluminum test data for the general evaluation phase of this contract, and continuing full size F-100 vane quick bonding in air process development. This in house work showed that the air bonding process was not feasible for blades or vanes when other dissimilar metals are in contact with the aluminum, such as a titanium spar, sheath or cover skin, inconel sheaths, and other steel components. Intermetallics and/or contamination can be formed between the interfaces of the dissimilar materials resulting in weak bonds. Therefore, the "quick vac" bonding process was developed to eliminate this problem. This process is essentially the same as the quick air bonding process except a vacuum atmosphere is used.

Based on the above data, the contract was changed to "quick vac" bonding for the remaining advanced evaluation and characterization phases.

1.2 BACKGROUND

Advanced Composite aluminum matrix fan blades offer significant payoff to Air Force systems in terms of both cost saving and performance improvements. However, there are currently problems which must be overcome prior to the introduction of such blades to service. Two problem areas have been identified for solution before aluminum matrix composites can be applied to Air Force weapon systems - high cost and inadequate FOD resistance. Low cost bonding fabrication techniques have been identified, and feasibility demonstrated. Improved FOD resistance of boron aluminum composites has been explored on laboratory specimens and full size blades. This program will combine the previously identified solutions to FOD resistance with low cost bonding fabrication to provide a basis for validation of these technologies for future fan blade hardware.

1.3 PROGRAM PLAN

The program was organized in two tasks as follows:

A. Screening

1. General Evaluation

- a. 8 mil and 5.6 mil Boron fiber
- b. 1100 and 6061 Aluminum Metal Matrix
- c. CMC and AVCO Fiber

2. Advanced Evaluation

- a. Select 2 most promising systems from above
- b. Conduct fatigue, thermal cycle, rupture, and impact tests to delineate best system.

B. Characterization

1. Select best system from IB above.

2. Conduct UTS and modulus tests on 0° and 90° orientation specimens at RT and 450°F, after thermal cycling, and salt fog; conduct RT inplane shear tests on 0° orientation. Conduct UTS and modulus tests on the blade orientation specimens at RT and 450°F, after thermal cycling, inplane shear, and tension-tension fatigue; conduct creep and stress rupture at 450°F, and stress corrosion tests.

The scheduled time for completion was 9 months, starting from June 20, 1975.

SECTION 2.0 GENERAL EVALUATION

2.1 RESULTS AND DISCUSSIONS

2.1.1 Process Development

2.1.1.1 Materials - Four tape systems were evaluated in this program: 8 mil B/6061, 8 mil B/1100, 5.6 mil B/6061 and 5.6 mil B/1100. Besides the two aluminum alloy matrices, two 8 mil and one 5.6 mil boron fibers were used; the 5.6 and one 8 mil fiber manufactured by the Composite Materials Corporation and a second 8 mil manufactured by AVCO. The effort involved with the 8 mil Boron/6061/CMC fiber was undertaken as an internally funded IR&D project, whereas all other systems were investigated as part of this program. The 8 mil B/6061 and 8 mil B/1100 tapes has a fiber count of 94 ± 2 ends/inch, a fiber volume of 48.7 to 54% with a 2 mil backing foil. Each tape was 15" wide and 68" long. The 5.6 mil B/6061 and 5.6 mil B/1100 tapes has a fiber count of 140 ± 3 ends/inch, a fiber volume of $57.5 \pm 3\%$ with a 1 mil backing foil. Each tape was 15" wide and 68" long.

The following six systems were investigated:

- a. 8 mil B/6061/CMC Fiber
- b. 8 mil B/1100/CMC Fiber
- c. 8 mil B/6061/AVCO Fiber
- d. 8 mil B/1100/AVCO Fiber
- e. 5.6 mil B/6061/CMC Fiber
- f. 5.6 mil B/1100/CMC Fiber

2.1.1.2 Tape Quality - The Union Carbide Corporation (UCAR) prepared the plasma sprayed tapes for all six systems listed above. Plasma sprayed tape from the Composites Material Corporation was prepared for only the 8 mil B/6061/CMC fiber system. The 5.6 mil tape used 1 mil foil and the 8 mil tape used 2 mil foil and all tapes were 15 inches wide. Tapes were examined for:

- a. Fiber spacing: number of ends/inch and uniformity
- b. Plasma spray uniformity and thickness
- c. Volume percent of fiber
- d. Strength of as-received fibers used in making the tape
- e. Strength of fibers, extracted from the fabricated tape
- f. Percent of cracked or damaged fibers in the tape

2.1.1.3 Pressure Application - The following modes of pressure application were investigated.

- a. Immediate application of full pressure at room temperature.
- b. Immediate application of a contact pressure of 100 to 200 psi to peak temperature; full pressure for the remainder of the time.
- c. Immediate application of a contact pressure of 100 to 200 psi to 920°F; full pressure (5500 ± 500 psi) application at some temperature between 920°F and 980°F.
- d. Immediate application of a contact pressure of 100 to 200 psi to 920°F; pressure was raised in 1000 psi increments to 5000 ± 500 psi with 30 second dwell times between each incremental increase.
- e. Immediate application of a contact pressure of 100 to 200 psi to 920°F; application of pressure to 3000 psi at 940°F to 950°F, dwell for one minute; addition of 1500 psi, dwell for one minute; application of an additional 1000 psi for the remainder of the run, or a final pressure of 5500 psi.

2.1.1.4 Atmosphere - The following atmospheric bonding environments were investigated:

- a. Air
- b. Vacuum of 10^{-4} to 10^{-5} torr was used to provide baseline comparison data.
- c. "Quick-Vac" was added during program based on input from in-house F-100 vane process development. The vacuum used was 5×10^{-3} torr to 20×10^{-3} torr.

2.1.1.5 Temperature - The peak temperature which was held during application of full compaction pressure was controlled to + 10°F or better. The range of peak temperatures investigated varied from 915°F to 1045°F. The 6061 matrix panels were fabricated at peak temperatures from 915°F to 1035° whereas the 1100 matrix panel fabrication peak temperature varied from 1026° to 1045°F.

2.1.1.6 Dwell Times - The dwell times at maximum pressure and peak temperature were varied to prevent fiber degradation. Periods as short as 10 minutes or less were used at 1045°F and as long as 26 minutes at 915°F.

2.1.1.7 Heating and Cooling Rates - The heating and cooling rates are decidedly different for vacuum processing in comparison to air bonding. The following general rates were used:

- a. Heating:
 - (1) Vacuum process: 500°F/hour

2.1.1.7 (Continued)

- (2) Air process: 400°F/minute
- (3) "Quick-Vac" process: 400°F/minute

b. Cooling

- (1) Vacuum process: 100°F/hour to 500°F/hour
- (2) Air process: 1200°F/hour to 100°F/minute
- (3) "Quick-Vac" process: 400°F/minute

It should be noted that cooling curves are not linear but more closely resemble an exponential curve in which the cooling rate declines markedly as room temperature is approached. Initially all panels were measured with six to eight thermocouples to obtain an accurate survey of the temperature distribution over the surface of a panel. Once a uniform panel thermal profile to within $\pm 10^\circ\text{F}$ was achieved with 100% reproducibility, then panel temperatures were measured and recorded by two thermocouples attached to each panel. Also, upper and lower platen temperatures were recorded during fabrication, and surveys of thermal uniformity over the heated platen surfaces were made at regular intervals.

2.1.1.8 Compaction Technique - Six ply panels were made in which the tape plies were carefully tack welded at the corners to insure tape placement and alignment for each panel. In order to control panel configuration uniformity a floating pressure plate for containment and pressure transmittal was used for bonding most of the specimens. This is accomplished hydraulically, since the pressure plate arrangement consisted of a steel plate floating on contained molten aluminum. The air bonding hardware arrangement is shown in Fig. 1.

2.2 TEST PROGRAM

The program was divided into two major phases: I. Screening and II. Characterization, as illustrated in Fig. 2. The screening phase consists of two stages: A. General Evaluation and B. Advanced Evaluation. Fig. 3 shows the six composite systems that were tested in the general evaluation stage. Fig. 4 shows a typical general evaluation test plan for one of the composite systems. This test plan was used for all six composite systems. However, system A, 8 mil Boron/6061/CMC fiber, was tested in greater detail as part of an internally funded program. Also, systems of 8 mil Boron/1100/AVCO fiber were tested in greater detail than illustrated here. Fig. 4 shows how complete traceability of materials was maintained throughout the program from the starting fiber on the spool, the tape, the panel and to the tested specimen. This meticulous traceability made it possible to determine how starting fiber properties were influenced by processing at various stages of composite manufacturing such as: tape preparation, panel consolidation and specimen testing.

The second stage of the screening phase is the advanced evaluation. The various components of the advanced evaluation stage are illustrated in Fig. 5. The characterization

2.2 (Continued)

study is the second major phase of this program and will be conducted with the composite system that emerges as having the most potential on the basis of test results in the screening phase. The various tests to be performed for the characterization study are illustrated in Fig. 6.

2.3 TEST RESULTS

The general evaluation screening phase test data are presented in the following paragraphs for each of the six composite systems in this phase.

2.3.1 8 Mil Boron/6061/CMC Fiber

2.3.1.1 Tapes - Tapes for this system were supplied from two sources, CMC and UCAR. Data for the various tapes used are presented in Table 1.

a. CMC Tape: The spool fiber U. T. S. were quite high, however, fiber strength dropped after plasma spraying and recovered after diffusion bonding which will be discussed later. The structure of CMC tape #8.0-6061-2M-3 is illustrated in Fig. 7. A thin layer of plasma sprayed 6061 covered the fibers but very little plasma spray penetrated between the fibers. Obviously winding at 102 ends/inch was too tight to produce a good tape. Cutting of this tape and its handling was very difficult since fibers were not well bonded to the backing foil. The plasma spray coating in many instances, bridged the gap between the fibers and did not cover the surfaces between the fibers and exhibited considerable fiber touching.

b. UCAR Tape: The spool fiber U. T. S. were generally quite high. As with CMC tape, a sizeable drop in fiber strength occurred after plasma spraying. The fibers in the UCAR tape were more widely spaced 90.6 to 94 ends/inch and this permitted better compaction of tapes which will be discussed further in this report. Metallographic examination of the tape indicated the plasma spray coating was present on the sides of the fiber and on the foil surface between the fibers, as shown in Fig. 8. The fiber spacing was quite uniform and no fiber touching was observed in UCAR tape. This work indicated a fiber spacing of 94 ± 2 ends/inch was ideal for the optimum number of fibers that could be incorporated in a tape to yield good plasma spray coating of the fibers and complete densification in compaction.

2.3.1.2 Panels - A series of panels were prepared as part of this study. Six panels were made in vacuum and 18 panels were fabricated in air. Each panel has six plies of tape and one 2 mil ply of 6061 as a cover foil. The strength results are summarized in Table 2 and 2A.

For the closely wound CMC tape, it was not possible to eliminate porosity under the bonding conditions used. By adding a 1 mil 6061 foil insert between tape plies it was

2.3.1.2 (Continued)

possible to achieve 100% density; the foils supplied additional aluminum material to flow in the spaces around the fibers and thus alleviate the potential for porosity. The additional aluminum served to lower the volume percent of fiber in the composite and increase the per ply thickness to 9.7 mils but did not affect strength on the basis of normalized 50 V/° fiber strength properties, which compensates for variations in fiber percent. The more loosely wound UCAR tape could be bonded to a 100% dense multilayer composite, without the incorporation of an additional 1 mil 6061 foil between plies resulting in a per ply thickness of 9.0 mils.

Both the CMC and AVCO 8 mil fibers showed degradation after plasma spraying. As part of this program, United Technologies Research Center has evaluated the hot pressing parameter envelope versus various plasma spray tape systems and their resultant effect on the fiber strength. The procedure used for this evaluation is as follows:

- a. Wind 1 inch wide strips of fiber on a mandrel. See Fig. 9. Strips are labeled A, B, C & D.
- b. Each strip has several areas covered with asbestos paper prior to plasma spraying. Segments A-1, B-1, C-1, & D-1.
- c. The entire mandrel is plasma sprayed.
- d. Cut each strip into 5 inch long segments.
- e. Hot press each segment between heated platens at specific conditions. They were all pressed in air between preheated platens at 5000 psi pressure.
- f. Leach fibers from remaining specimens and test.

The material combinations investigated were:

Tape 1632	AVCO 8 mil fiber - 6061 aluminum
Tape 1634	AVCO 8 mil fiber - 1100 aluminum
Tape 1637	CMC 8 mil fiber - 6061 aluminum
Tape 1633	CMC 8 mil fiber - 1100 aluminum

The resultant fiber strength data are presented in Table 3. The data demonstrate very clearly that both 8 mil fibers exhibit the same degradation - recovery phenomenon characteristic as 4 and 5.6 mil fibers previously evaluated under Hamilton Standard IR&D.

2.3.1.2 (Continued)

- The level of degradation can be very severe.
- CMC fiber degraded significantly more than the AVCO fiber and in one case, T-1634-C-2, almost no degradation was noted.
- Both fibers can recover fully. However, not under all hot pressing conditions.
- Subsequent degradation can occur if the temperature is high and time is long. Refer to Table 3 for example T-1637-C, T-1633-C. This, however, occurs at times longer than those of interest for economical composite production.

2.3.1.2.1 Vacuum Bonding Panels - BSAd 1146, 1147, 1148, 1149, 1169, 1173. Of the six 6-ply panels fabricated in vacuum to provide "good" material baseline data, five panels were made under pressure, peak temperature and dwell times similar to the bonding cycles. For the range of fabrication parameters studied, there apparently was no great variation in tensile strength properties among the 0°, longitudinal tensile specimens. The following average strength and standard deviation properties were calculated:

Fiber Orientation	n	U. T. S., Normalized to 50V/° Fiber \bar{x} , KSI	σ , KSI
0°	10	199	17.7
90°	16	17.1	2.16

As can be seen in footnote 3, Table 2, these properties are comparable to those of panels fabricated in air. Figures 10 and 11 show typical microstructures for two panels, BSAd #1148 and #1169 fabricated at 1023°F and 915°F, respectively. Both panels looked similar and touching fibers are illustrated in Fig. 10 for BSAd #1148. Although rather limited data are available, it should be noted that the strength properties of panels made from CMC tape or UCAR tape are equivalent. A mechanical forepump that operates at 80 CFM and a 6" diameter NRC oil diffusion pump was used. The pump down time to 20×10^{-3} torr averaged two minutes.

2.3.1.2.2 Air Bonding Panels - BSAd 1151, 1152, 1153, 1154, 1164, 1167, 1168, 1176, 1177, 1178, 1180, 1181, 1198, 1199, 1200, 1233. These 6 ply panels were fabricated over a range of peak temperatures, 998°F to 1030°F, at pressures from 5 KSI to 6 KSI and for times ranging from 1.5 minutes at 1030°F to 14 minutes at 998°F. Within the framework of these parametric variables and the various fabrication cycles used, as given in Table 2, no significant variations in tensile strength occurred for the longitudinal or transverse directions with one possible exception.

Panel BSAd #1164 fabricated at 1030°F, was the only one to exhibit consistently low transverse strength for more than one specimen in a test series, see Table 2. The

2.3.1.2 (Continued)

microstructure of BSAd #1164 is illustrated in Fig. 12. For comparison, panel BSAd #1154, made from CMC tape is shown in Fig. 13 and a panel, BSAd #1168, is shown in Fig. 14. All three panels exhibited complete compaction and appeared to be quite similar. However, BSAd #1164 was different in one respect, a segment from BSAd #1164 contained almost three times as many cracked fibers as segments from BSAd #1154 or BSAd #1168, i.e., 32.7% extracted cracked fibers from a panel segment versus 11.2% and 11.8% for the other two panels. The following average strength and standard deviation properties were calculated for specimens taken from the 18 panels:

Fiber Orientation	n	U. T. S., Normalized to 50V/° Fiber	
		\bar{x} , KSI	σ , KSI
0°	49	196	20.5
90°	41	17.2	4.05

These properties are comparable to those of panels fabricated in vacuum. It also should be noted that the strength properties of panels made from CMC tape or UCAR tape are equivalent for air bonding.

Based on this data, the air bonding process can produce panels with tensile properties equivalent to those of vacuum processed panels.

A limited number of tests were run with specimens from air bonded panels to determine tensile modulus properties. The following average properties were calculated:

Fiber Orientation	n	Av. Tensile Modulus
		PSI x 10 ⁶
0°	3	34.8
90°	2	17.9

Based on the above results, an air bonding process was selected for the General Evaluation portion of the program. This fabrication process was selected to permit bonding at a safe peak temperature for times and pressures that would not degrade the boron fiber by interaction with the aluminum alloy matrix. The standardized cycle selected was:

- Insert the layup between preheated platens. The preheated platens were usually at 35°F ± 10°F above the desired peak temperature for the processing cycle.
- Apply a contact pressure.

2.3.1.2 (Continued)

c. When layup is at 930°F to 950°F, apply a compaction pressure of 3000 psi, dwell for one minute; apply additional 1500 psi, dwell for one minute; apply additional 1000 psi (5500 psi total).

d. Continued heating to peak temperature of $1010 \pm 10^\circ\text{F}$ and hold at peak temperature for 10 minutes.

e. Separate platens and remove part immediately.

f. Cool part rapidly by placing on steel plates and directing stream of compressed air over it.

2.3.1.2.3 "Quick-Vac" Bonding Panels: BSAd 1233R, 1233RR - These panels were fabricated under conditions that were designed to yield sound bonding and alleviate the deleterious oxidation that is promoted in air and which hinders the attainment of a good bond between boron/aluminum and Ti-6Al-4V. The "Quick-Vac" processing is similar to that of the air bonding cycle except that a vacuum chamber is used and immediately after placing the layup between preheated platens, which are maintained 50°F below the final peak pressing temperature at this stage of the process, the chamber is rapidly evacuated to a rough vacuum during this time period and the heating cycle is "hesitated" i.e., power is not supplied to platens. Once the layup is at 950°F, compaction pressurization, thermal cycling and part removal is carried out essentially the same as described for the "standardized" air bonding cycle. The average values for room temperature tensile properties for two panels are listed below:

Fiber Orientation	n	U. T. S., Normalized to 50 V/° Fiber		Av. Tensile Modulus PSI x 10 ⁶
		, KSI	, KSI	
0°	4	202	---	34.9
90°	4	24.9	2.2	24.9

It can be observed in Table 11 that the static tensile room temperature properties for the 6061/8 mil Boron/6061/CMC fiber system are essentially equivalent regardless of the fabrication environment used, i.e., air bonding, vacuum bonding or "Quick-Vac" bonding.

The 450°F tensile properties are presented in Table 2A. In comparison to the room temperature properties, the 450°F tensile strengths exhibited declines of approximately 10% and 25% for the longitudinal and transverse directions respectively. The 450°F longitudinal tensile modulus exhibited no appreciable decline, whereas the transverse tensile modulus evinced about a 30% decrease at 450°F. Comparable air, vacuum, and "Quick-Vac" and 450°F data, is shown in Table 11.

2.3.2 8 Mil Boron/6061/AVCO Fiber

2.3.2.1 Tape - UCAR Tape #2922-21 was used for preparing panels for this portion of the program by the standardized process. This tape was prepared from AVCO fiber from spools: 25B-73, 27B-79-B, 27B-79-M and 27B-40. This tape was used to prepare panels, BSAd #1215, 1216, and 1217. Fiber strengths have been summarized in Table 4 and includes: (a) vendor spool data, (b) Hamilton Standard "Q.C." spool check, (c) fiber strength for fibers extracted from panels, BSAd #1215 and 1217.

Comparison of the strength data indicated that the "Q.C." spool check values were generally higher than the values supplied by the vendor. It is important to note that panel fabrication, using the "standardized" cycle described previously, did not cause fiber degradation. In fact, for fibers extracted from panels BSAd #1215 and 1217, the average strength for both groups of fibers was 517 KSI.

The microstructure of tape, UCAR #2922-21, is shown in Fig. 15. This tape resembled tape UCAR #2873-55, Fig. 8, in appearance although different fibers were used in their respective constructions. Visually, there was little or no difference between fiber features.

2.3.2.2 Panels - Room temperature tensile strength and impact data for this system are presented in Table 5. Because the 90° impact values were quite low, it was difficult to measure peak loading, P max.; also it was not meaningful to calculate the bend strength or energy's absorbed per unit area. The average room temperature tensile strength properties calculated for specimens taken from the prepared panel are presented in Table 10. These values are quite similar to the corresponding average strength values reported previously for the 8 mil Boron/6061/CMC fiber system, however, the latter system did exhibit slightly lower transverse, 90° fiber orientation, properties. Although the 8 mil Boron/6061/AVCO fiber system possessed slightly higher transverse tensile strength properties, it also exhibited extensive fiber splitting in the transverse tensile specimens, whereas the 8 mil Boron/6061/CMC fiber system did not. This apparently was the biggest difference between the two fibers, when consolidated in a 6061 aluminum alloy matrix. Examination of panels BSA #1215, 1216 and 1217 indicated complete densification. A typical microstructure is shown in Fig. 16 for BSAd #1215; this structure appeared quite similar to that of panels made from the previous system. Fig. 17 shows the RT 90° tensile test specimens with fiber splitting. Fig. 18 shows the 0° and 90° impact test specimen with fiber splitting on the 90° specimen.

The 450° tensile strength properties also are presented in Table 5. In Table 11 the calculated average 450°F properties are summarized. The 450°F static tensile strengths exhibited approximate declines of 10% and 30% for the longitudinal and transverse directions, respectively, in comparison to the corresponding room temperature properties. The 450°F longitudinal tensile modulus showed almost no decrease and

2.3.2.2 (Continued)

the transverse tensile modulus declined by only 10%. These 450°F values are quite similar to the corresponding average tensile strength values reported for the 8 mil B/6061/CMC fiber system fabricated by "Quick-Vac" bonding. The only noticeable difference in properties was that the 450°F transverse strength of the "Quick-Vac" bonded 8 mil B/6061/CMC fiber system was about 20% greater than that of the 8 mil B/6061/AVCO fiber system.

2.3.3 8 Mil Boron/1100/AVCO Fiber

2.3.3.1 Tape - UCAR Tape #2922-27 was used for preparing three panels made using the "standardized" processing cycle and UCAR tape #2922-28 was used for preparing a fourth panel bonded at a higher "peak" temperature. Tape #2922-27 was prepared from AVCO fiber from spools: 25B-68, 27B-8H and 27B-57. This tape was used to prepare panels, BSAd #1212, 1213 and 1214. Tape #2922-28 was prepared from ACVO fiber from spool: 27B-57. This tape was used to prepare an additional panel BSAd #1218. Fiber strength for tape #2922-27 have been summarized in Table 4 and include fiber strength for fibers extracted from panels, BSAd #1212 and 1214. Comparison of the strength data indicated that the "Q.C." spool check values were about the same as values supplied by the vendor. Panel processing using the "standardized" cycle described previously apparently caused a slight decline in fiber strength as shown in Table 4 for panel extracted fibers. The average tensile fiber strength for both groups of extracted fibers was 434 KSI; a definite decline from the 529 KSI spool "Q.C." strength. However, this decline was not considered of significant magnitude to be designated a degradation of fiber strength. The microstructures of tapes, UCAR #2922-27 and UCAR #2922-28 are shown in Fig. 19 and 20 respectively. Visually these tapes are similar to UCAR #2922-21, Fig. 15, despite the use of somewhat different alloy matrices.

2.3.3.2 Panels - As shown in Table 6, the three panels BSAd #1212, 1213 and 1214 that were prepared using the "standardized" processing cycle exhibited quite poor room temperature transverse tensile strength. Therefore a fourth panel BSAd #1218 was prepared using a much higher peak temperature 1035°F in an attempt to improve transverse tensile strength. This processing change did not increase the transverse tensile significantly, as shown in Table 6A, but did improve the tensile modulus somewhat. With respect to longitudinal strength, the tensile declined but the modulus increased somewhat. No explanation is readily apparent. The average room temperature tensile strength properties calculated for specimens taken from panels prepared by both methods of processing are presented in Table 11.

In comparison to 8 mil Boron/6061 systems made with CMC or AVCO fibers, both process cycles of the 8 mil Boron/1100/AVCO fiber system were inferior with respect to tensile strength in either the longitudinal or transverse fiber directions. This was

2.3.3.2 (Continued)

markedly obvious for the transverse tensile strength properties. Also, "standardized" processing resulted in lower tensile modulus for both fiber directions, whereas processing at a higher temperature did not. The 450°F tensile mechanical properties for both versions of this system are presented in Tables 6 and 6a. The calculated average 450° properties are listed in Table 11. It can be observed that there were no great differences between the composites processed by either method, although the 450°F transverse modulus of the higher peak temperature processed material was larger. At 450°F, almost every static tensile property experienced a decrease in value compared to its room temperature counterpart in comparison to the 8 mil Boron/6061 systems made with either CMC or AVCO fibers, both versions of the 8 mil Boron/1100/AVCO fiber system were generally inferior at 450°F in terms of tensile strength and tensile modulus for both the longitudinal and transverse directions.

With respect to room temperature impact properties, it can be observed that the 90° energy absorbed values were approximately the same for the 8 mil B/1100/AVCO fiber system regardless of the processing cycle used. Comparison of the impact properties of this system to that of the 8 mil Boron/6061/AVCO fiber system indicated that:

- a. For the 90° orientation, the 8 mil Boron/6061/AVCO fiber panels exhibited higher absorbed energy values by a factor of 2X and 3X.
- b. For the 0° orientation, the 8 mil Boron/6061/AVCO fiber panels exhibited somewhat greater absorbed energy and absorbed energy per unit area values.

Examination of panels BSAd #1212, 1213, 1214 and 1218 indicated complete densification. A typical microstructure is presented in Fig. 21 for BSAd #1212; this structure was similar to that of panels representative of the 8 mil Boron/6061/AVCO system. Fig. 22 shows the RT 90° tensile specimens and Fig. 23 shows the RT 0° and 90° impact specimens after test.

2.3.4 8 Mil Boron/1100/CMC Fiber

2.3.4.1 Tape - UCAR Tape #2922-12 was used for preparing three panels made using the "standardized" processing cycle. Tape #2922-12 was prepared from CMC fiber from spools: 14A-890, 14A-880, 14A-879 and 14A-864. This tape was used to prepare panels, BSAd #1209, 1210 and 1211. Fiber strengths have been summarized in Table 4 and include fiber strengths for fibers extracted from panels, BSAd #1209 and 1210. Comparison of the strength data indicated that the "Q.C." spool check values were lower by 78 to 117 KSI for spools 14A-879 and 14A-864 than the vendor supplied values. Panel processing using the "standardized" cycle caused a decline in fiber strength as shown in Table 4 for panel extracted fibers. The average tensile fiber strength for both groups of extracted fibers was 376 KSI; a decline from the 504 KSI

2.3.4.1 (Continued)

average of the spool "Q.C." fiber strengths. The microstructure of tape, UCAR #2922-12 is shown in Fig. 24. Visually this tape is similar to tapes, UCAR #2922-27 and UCAR #2922-28, shown in Figs. 19 and 20 respectively.

2.3.4.2 Panels - Room temperature tensile strength and impact data for this system are presented in Table 7. It is obvious from Table 7 that the transverse tensile strengths are quite low. The average room temperature tensile strength properties for specimens taken from the panels are tabulated in Table 11.

In comparison to the data for the prior 8 mil Boron/1100/AVCO fiber systems, it would appear that the longitudinal tensile strength was slightly lower for the CMC fiber system but the modulus was in the range of values reported. The transverse tensile strength and modulus for the CMC fiber system was within the range of values reported for the two corresponding AVCO fiber systems. Thus, the room temperature tensile properties for both fiber systems in an 1100 aluminum alloy matrix are approximately equivalent. With respect to room temperature impact properties for both the 0° and 90° orientations, the 8 mil B/1100/CMC fiber system exhibited property values that were almost identical to those of the 8 mil B/1100/AVCO fiber systems. The 450°F tensile mechanical properties are presented in Table 7 and the calculated average 450°F properties are summarized in Table 11. It should be noted that considerable difficulty was encountered in testing these specimens due to breakage in grips and strain gage failures. The static tensile properties measured at 450°F were generally lower than the room temperature properties for both the longitudinal and transverse directions. In comparison to the 450°F properties of the 8 mil B/1100/AVCO fiber system, the average longitudinal tensile strength of this system was considerably lower whereas the modulus was equivalent. The 450°F transverse properties of this system were within the range of 450°F tensile strength properties determined for the 8 mil Boron/1100/AVCO fiber system. Examination of panels BSAd #1209, 1210 and 1211 indicated complete densification: A typical microstructure is presented in Fig. 25 for BSAd #1209. This structure was similar to that of panels representative of the 8 mil Boron/1100/AVCO fiber systems. Fig. 26 shows the 0° and 90° tensile specimens with no split fibers on the 90° specimen and Fig. 27, the 0° and 90° impact specimen also showing no split fiber on the 90° specimen.

2.3.5 5.6 mil Boron/6061/CMC Fiber

2.3.5.1 Tape - UCAR Tape #2922-20 was used for preparing panels for this portion of the program. This tape was prepared from CMC fiber from spools: 6-2654 and 14A-867. The tape was used to prepare panels, BSAd #1219R, 1220 and 1221. Fiber strengths have been summarized in Table 4 and include strengths for fibers extracted from panels, BSAd #1220 and 1221. Comparison of the strength data indicated that the "Q.C." spool check values were in agreement with the vendor spool values. Also,

2.3.5.1 (Continued)

fabrication by the "standardized" processing cycle did not cause a significant decline in the strength of panel extracted fibers. Since 5.6 mil boron was used, this tape was constructed to contain approximately 140 turns per inch and the backing foil was 1 mil 6061 aluminum alloy. The microstructure of tape, UCAR #2922-20 is shown in Fig. 28.

2.3.5.2 Panels - Room temperature tensile strength and impact data for this system are presented in Table 8. The tensile strength data were normalized to 50 V/° fiber for comparison to the 8 mil boron system. The average room temperature tensile mechanical properties for specimens taken from the panels are presented in Table 11.

In comparison to the data for the two 8 mil Boron/6061 systems, the 5.6 mil Boron/6061 system possessed superior tensile strength and moduli for both the longitudinal and transverse directions. The tensile strengths of the 5.6 mil Boron/6061 system was about 20 to 25% greater than the corresponding strengths of the 8 mil Boron/6061 system, whereas the tensile moduli proved to be 20 to 30% greater than those of the 8 mil Boron/6061 systems. With respect to the 8 mil Boron/1100 systems, the strength advantages of the 5.6 mil Boron/6061 system were generally more pronounced than for the 8 mil Boron/6061 systems.

The 450°F tensile strength properties are listed in Table 8 and the calculated average 450°F properties are summarized in Table 11. The 450°F static tensile strength properties exhibited approximate declines of 23% and 38% for the longitudinal and transverse directions, respectively, in comparison to the corresponding room temperature properties. The 450°F longitudinal tensile modulus exhibited only a slight decrease; whereas the transverse modulus declined by greater than 30% at 450°F. Interestingly, at 450°F on the basis of 50 V/° normalized properties the 5.6 mil Boron/6061/CMC fiber system was not superior to either the 8 mil B/6061/CMC fiber system or the 8 mil B/6061/AVCO system. The previously discussed room temperature strength advantages of the 5.6 mil Boron/6061 system apparently for the most part have been dissipated at 450°F.

The impact properties for the 5.6 mil B/6061/CMC fiber system are similar to those of both the 8 mil B/6061 systems for both the 0° and 90° orientations, and consequently superior to the 8 mil B/1100 systems for the 90° orientation. A typical microstructure is shown in Fig. 29, BSAd #1221. Fig. 30 shows the RT 0° and 90° tensile specimens showing no 90° fiber splitting and the RT 0° and 90° impact specimens shown in Fig. 31 exhibit no fiber splitting on the 90° specimen.

2.3.6 5.6 Mil Boron/1100/CMC Fiber

2.3.6.1 Tape - UCAR Tape #2922-16 was used for preparing the required test panels. This tape was prepared from CMC fiber from spools: 14A-865 and 14A-866. The tape was used to prepare panels by the standardized process, BSAd #1224, 1225 and 1226.

2.3.6.1 (Continued)

Fiber strengths have been summarized in Table 4. The "Q.C." spool check values indicated that both fiber lots exceeded the 450 KSI minimum by at least 85 KSI. This tape contained 5.6 mil boron and was constructed to contain approximately 140 turns per inch and the backing foil was 1 mil 1100 aluminum alloy. The microstructure of tape, UCAR #2922-16, is shown in Fig. 32.

2.3.6.2 Panels - Room temperature tensile and impact data for this system are presented in Table 9. Both the longitudinal and transverse strengths were significantly lower for the 5.6 mil B/1100/CMC fiber system than for the 5.6 mil B/6061/CMC fiber system. The average room temperature tensile strength properties calculated for specimens taken from the panels are presented in Table 11.

In comparison to the strength data for the two 8 mil Boron/1100 system, this 5.6 mil Boron/1100 system possessed nearly equivalent tensile strengths for the corresponding longitudinal and transverse directions. This system showed lower tensile strength properties than the 8 mil Boron/6061 system. The 450°F tensile mechanical properties are presented in Table 9 and the calculated average 450°F properties are summarized in Table 11. Again it should be noted that considerable difficulty was encountered in the elevated temperature testing in two respects. Strain gage failures occurred repeatedly and invalidated many of the efforts to obtain a measure of tensile modulus and strain to failure. The other problem was that five of six transverse specimens failed on gripping. Only the transverse tensile strength at 450°F was lower than the corresponding room temperature transverse tensile strength. All other properties appeared about equivalent. In comparison to the 450°F properties of the 5.6 mil Boron/6061/CMC fiber system, this system was decidedly inferior.

The impact properties of the 5.6 mil Boron/1100 system were about the same as both 8 mil Boron/1100 systems and consequently inferior to all three 6061 matrix systems for the 90° orientations.

A typical microstructure is illustrated in Fig. 33, BSAd #1226. Fig. 34 shows the RT 0° and 90° tensile specimen with no fiber splitting on the 90° specimen, and Fig. 35, the RT 0° and 90° impact specimens with no fiber splitting.

2.3.7 Quality Control

Two tentative composite tape specifications were prepared, and they are included in Appendix A.

- a. Tape Specification Number HS 7108 for 6061/8 Mil B/6061 tape.
- b. Tape Specification Number HS 7109 for 1100/8 Mil B/1100 tape. Copies of the specifications have been circulated to the fiber and tape vendors for comments. A copy of each specification is included in Appendix A and B.

2.4 Summary and Conclusions of General Evaluation

2.4.1 Average Longitudinal U. T. S. Properties

a. Room Temperature - As shown in Fig. 36, the average U. T. S. for the 5.6 mil Boron/6061 was greater than all other systems. Also the three 6061 matrix systems, 5.6 mil Boron/6061, 8 mil Boron/6061/CMC fiber and 8 mil Boron/6061/AVCO fiber were stronger than the 1100 matrix systems. In the 6061 systems, the AVCO and CMC 8 mil boron fibers shown approximately equivalent composite panel strength. Also, air bonding and "Quick-Vac" appeared to be equivalent processes. Interestingly, in the 1100 matrix system, the 5.6 mil boron composite exhibited the lowest longitudinal tensile strength.

b. 450°F - The three 6061 matrix systems, appeared to possess approximately the same average longitudinal strength at 450°F regardless of fiber source, AVCO and CMC; or fiber diameter, 5.6 mils vs. 8 mils. Interestingly, the distinct strength advantage at room temperature enjoyed by the 5.6 mil Boron/6061/CMC fiber system over the other two 6061 matrix systems was nonexistent at 450°F. See Table 11. The strength properties of the three 1100 matrix systems were all lower than those of the 6061 matrix systems.

2.4.2 Average Longitudinal Elastic Moduli

a. Room Temperature - As shown in Fig. 37, the 5.6 mil boron system exhibited the largest moduli properties. The moduli of the 8 mil Boron/6061 systems were not as great as the 5.6 mil boron systems but were greater than either 8 mil Boron/1100 systems. The data for all the systems indicated that the CMC fiber systems were either equivalent or slightly better than the corresponding AVCO fiber system but not significantly better.

b. 450°F - The 5.6 mil Boron/6061 system retained its superiority at 450°F compared to the 8 mil boron 6061 matrix systems. The 8 mil Boron/6061 system moduli were greater than either of the 8 mil Boron/1100 systems. The 450°F data failed to indicate that one fiber system was superior to the other, as shown in Fig. 37.

2.4.3 Average Transverse U. T. S. Properties

a. Room Temperature - The 5.6 mil Boron/6061 system exhibited the best transverse tensile strength properties as shown in Fig. 38. Both 8 mil B/6061 systems were superior to their 8 mil B/1100 system counterparts. The 8 mil Boron/6061/AVCO fiber system was slightly better than the air bonded 8 mil Boron/6061/CMC fiber system but only equivalent to the "Quick-Vac" bonded 8 mil (B/6061/CMC fiber system. The 8 mil Boron/6061/AVCO system exhibited gross distinct fiber splitting.

2.4.4 Average Transverse Elastic Moduli

a. Room Temperature - The 5.6 mil Boron/6061 system demonstrated the best average transverse elastic moduli value as illustrated in Fig. 39. It should be noted that the moduli of the 8 mil B/6061 systems were greater than those of the 8 mil B/1100 system counterparts. The moduli for the air bonded 8 mil Boron/6061 systems were approximately equivalent, indicating that the type of fiber used in the composite had no discernible influence on the moduli properties.

b. 450°F - The 5.6 mil Boron/6061 system did not retain its room temperature transverse modulus superiority to 450°F. At this temperature, the moduli of the three 6061 matrix systems were approximately equal. The moduli of the 8 mil Boron/6061 systems were greater than their 8 mil Boron/1100 system counterparts. Also, the moduli for both 8 mil Boron/6061 systems were equivalent at 450°F.

2.4.5 Impact Energy

On an overall basis, the 6061 matrix specimens provided superior impact performance when compared with all of the 1100 matrix specimens. Referring to Table 10, it can be seen that the three point bend strength (B in the table) was significantly greater for the 6061 matrix specimens and also, that the measured values of energy dissipated per unit volume of specimen (E in the table) were as great as those for the best 1100 performance. Also in Table 10 can be found a comparison of bend strength (B) with tensile strength. All composites except the 5.6 B/6061 system, exhibited a ratio of B/T of approximately 1.4. Finally, the elastic energy per unit volume stored in each bend specimen at its failure load was calculated and tabulated in Table 10 as (E1). These values were compared with the total energy dissipated as measured (E) and it was found that the former accounted for approximately 50% of the latter. This percentage was highest for the highest strength system and would decrease substantially as impact specimens were made thicker.

a. Specimens were always 0.394 inches wide, 2.2 inches minimum length, 6 plies thick. The specimen thickness was the thickness of the panel. Instrumented charpy impact tests were conducted with a 23 ft-lb capacity unit in which the striker was instrumented with strain gages. The strain gages measured the elastic deformation of the striker during impact. These readings were converted into lash applied to the impact specimen.

As shown in Fig. 40, when the impact energy absorbed is evaluated on a per unit area basis, five of the six systems were roughly equivalent in their behavior. Neither the type of fiber, CMC vs. AVCO, the fiber size, 8 mil vs. 5.6 mil, or the aluminum alloy matrix, 6061 vs. 1100, exerted any significant influence on the resulting impact energy absorbed/area.

2.4.6 Fiber Influence

Based on this preliminary data, it would appear that the CMC and AVCO 8 mil boron fibers behaved similarly when incorporated in identical alloy matrix systems. The only exception being that the AVCO fiber evidenced splitting when tensile tested in the transverse direction. A more significant factor than the fiber source appeared to be the alloy matrix used for incorporating the fibers. On the basis of the properties studied, it can be tentatively concluded that the 6061 aluminum alloy is a more promising matrix than the 1100 alloy for both 8 mil and 5.6 mil boron fibers.

SECTION 3.0 ADVANCED EVALUATION

3.1 RESULTS AND DISCUSSIONS

In this phase of the work the two most promising systems developed in the preceding general evaluation phase were selected on the basis of superior mechanical properties, fabrication capability and cost reduction potential. The 8 mil Boron/6061/CMC fiber and the 8 mil Boron/6061/AVCO fiber systems satisfaction fulfilled the above objectives. Both tape systems were manufactured by UCAR per Hamilton Standard specification Hamilton Standard 7108 to 15" widths. This effort involved a six stage program which is presented in Fig. 5. In addition, the process was changed from air bonding to "Quick Vac" bonding for the advanced evaluation section. This change resulted from air bond IR&D work at Hamilton Standard on F-100 blades and vanes. This work showed that air bonding boron aluminum components that have either titanium or steel in contact with the aluminum presents a potential intermetallic and contamination problem, making the air bonding process impractical for boron aluminum blade design that incorporates titanium or steel. The "Quick Vac" process was developed under the IR&D program to eliminate this problem.

3.1.1 Processing

All panels were prepared using the "Quick Vac" fabrication technique previously mentioned and discussed in the process development section for 8 mil Boron/6061/CMC fiber, paragraph 2.3.1.2.3.

3.1.2 Test Program and Results

As indicated in Fig. 5, this program was divided into six stages: thermal cycling, stress rupture, axial fatigue, flexural fatigue, panel impact, and fabrication demonstration. These six test items will be discussed in order for each of the two systems involved.

3.1.2.1 Thermal Cycling - Longitudinal, 6 ply specimens from the 8 mil/Boron/6061/CMC fiber and 8 mil Boron/6061/AVCO fiber systems were subjected to 1000 thermal cycles. Each cycle consisted of a thermal variation from -65°F to 450°F. After 1000 cycles, the specimens were tensile tested at room temperature. The following results were obtained:

3.1.2.1 (Continued)

Fiber System	Specimen No.	V/°	U. T. S. in KSI	Normalized to 50 V/°		Modulus psi X 10 ⁶	% in./in
				Fiber U. T. S. in KSI	U. T. S. in KSI		
CMC	1258A-L1	50.8	190	187		32.0	0.68
CMC	1258A-L2	50.8	193	190		31.0	0.65
AVCO	1243B-1	50.4	- (1)				
AVCO	1243B-2	50.5	- (1)				

(1) Unable to test due to some warpage and twist.

As indicated in the above summary, the specimens for the 8 mil Boron/6061/AVCO fiber system could not be tested due to the occurrence of warpage and twisting as a result of thermal cycling. This was not unusual, since it occurred again in the characterization phase of this program. We are not sure what caused the warpage, but after further evaluation and discussions, there appears to be several possible causes for the warpage as follows:

a. Larger thermal gradient between specimens than anticipated during thermal cycle because of overcrowding of the basket in the thermal cycle facility.

b. The AVCO fiber had a large variation in diameter from 7.8 mils to 8.25 mils as compared to the CMC fiber which varied from 7.9 to 8.1. If a specimen had max. diameter fibers on one side and min. diameter fiber on the other side of specimen, this would cause an unbalance in the specimen, which could cause warpage.

With respect to the specimens that could be tested, apparently the thermal cycling had a slight affect on the resultant tensile properties. Comparison of these strength values with averages given in Table 11 for the corresponding system indicated the strength may have decreased about 5% and the modulus by 10% as a result of thermal cycling. However, the tensile strength decline is considered to be within the margin of variation for experimental testing and materials variability.

3.1.2.2 Stress Rupture - Longitudinal and transverse specimens from the 8 mil Boron/6061/CMC fiber and 8 mil Boron/6061/AVCO fiber systems were subjected to stress rupture testing at 450° F. All specimens were unidirectional and contained six tape plies.

3.1.2.2.1 Test Results - All test results are listed in Table 12 for both fiber systems. This data was used to construct semilogarithmic plot of the rupture stress as a function of log time. Also, two Larson-Miller plots were constructed. In Table 12 specimens that were stress at lower levels and obviously would not fail for thousands of hours are indicated as terminated in Table 12 and most of these points were not plotted when they fell far below the curve based on fractured specimens.

In Fig. 41, it can be observed that the CMC fiber system exhibited a generally lower stress rupture strength than the corresponding AVCO fiber system for the longitudinal fiber direction. Both systems seemed to behave similarly with respect to rupture life variation as a function of applied stress. Interestingly, the 5.7 mil Borsic/6061 system investigated previously at Hamilton Standard exhibited a similar behavior in terms of rupture life at 600°F as a function of applied stress. Boron/aluminum composites at these fiber volume levels and this orientation characteristically exhibit a rather shallow slope for semilogarithmic plots of rupture stress as a function of log time.

For the transverse fiber direction, it can be observed that both fiber systems exhibited almost identical stress rupture behavior as shown in Fig. 42. Furthermore, these systems showed a similar but not identical variation in rupture life as function of applied stress as the 5.7 mil Borsic/6061 system at 600°F. This should be expected since the alloy matrices are the same and the fiber contents are quite similar for all the systems involved.

This data has been analyzed to calculate the 10, 100 and 1000 hour stress rupture values tabulated below.

<u>System</u>	<u>Rupture Life, Hours</u>	<u>Rupture Stress in KSI</u>	
		<u>Longitudinal</u>	<u>Transverse</u>
8 mil B/6061: CMC Fiber	10	142.0	6.43
	100	140.5	6.20
	1000	137.8	5.84
8 mil B/6061: AVCO Fiber	10	169.0	6.43
	100	166.2	6.20
	1000	163.4	5.84

The data have been used to construct the Larson-Miller plots presented in Figs. 43 and 44 for the longitudinal and transverse test directions, respectively.

In some cases it became apparent that the specimens would not fail in a 1000 hours or less and these tests were terminated. Several of these specimens were subsequently tensile tested at room temperature to ascertain if the stress rupture testing had significantly altered their properties. The following room temperature tensile results were obtained:

3.1.2.2.1 (Continued)

<u>Fiber System</u>	<u>Specimen No.</u>	<u>Rupture Stress KSI</u>	<u>Duration Hrs.</u>	<u>Fiber V/°</u>	<u>U. T. S. in KSI</u>	<u>Normalized to 50 V/° Fiber U. T. S. in KSI</u>
AVCO	1238-L2	133.9	1121.5	49.6	205	207
AVCO	1238-L4	160.4	690.7	49.5	204	206
CMC	1237-L2	134.1	1754.8	49.8	190	191

The results indicated that subjection to the 450°F stress rupture test conditions was not particularly adverse to the composites; their post-exposure room temperature tensile strengths were not lowered as can be seen by comparison with corresponding systems in Table 11.

3.1.2.3 Fatigue Tests - Six-ply longitudinal and transverse specimens with 8 mil Boron/6061/CMC fiber and 8 mil Boron/6061/AVCO fiber were fabricated by the "Quick Vac" technique as discussed in paragraph 2.3.1.2.3 Fig. 45 shows the fatigue test specimen. These specimens were subjected to tension-tension and flexural fatigue tests at room temperature.

3.1.2.3.1 Test Procedure - The tension-tension tests were conducted in Budd Axial Fatigue Machine under $R = 0.1$ conditions. The specimens were run at predetermined stress levels to 10^7 cycles or fracture. The stresses were based on P/A values.

The flexural fatigue tests were conducted in the CB free-free-beam machines under reversed bending conditions. The 0° specimens were tests in incremental stress levels of 80,000, 100,000, 120,000 and 140,000 psi until a 5% change in beam natural frequency occurred. The beam natural frequency was determined by attaching to it a very small magnetically sensitive mass and exciting the beam through this with a small oscillator driven electromagnetic vibrator. A proximity pickup probe served as a resonance indicator. This process was done initially and at the end of each test level after 10^7 cycles.

3.1.2.3.2 Test Results

Tension-Tension Test (0° Fiber) - The results are shown in Fig. 46. The AVCO fiber specimens show a typical strength at 10^7 cycles of about 88,000 psi. The CMC fiber specimens show a strength of 94,000 psi. Two specimens made with each fiber endured 10^7 cycles at 80,000 psi without incident.

3.1.2.3.2 (Continued)

Tension-Tension Test (90° Fiber) - The results are shown in Fig. 47. The AVCO fiber specimens show a typical strength of approximately 8500 psi at 10^7 cycles. The CMC fiber specimens show a strength of about 8800 psi. One specimen made from each fiber endured 10^7 cycles at 9000 psi without incident.

Flexural Fatigue Test (0° Fiber) - The results are shown in Fig. 48. Based on the average of three specimens, the points plotted show that by incremental testing to $\pm 140,000$ psi, cumulative fatigue damage lowered the specimen natural frequencies by 5% at about 118,000 psi and 125,000 psi for the CMC and AVCO fibers, respectively.

Flexural Fatigue Test (90° Fiber) - The results are shown in Fig. 49. The AVCO fiber specimens show a typical strength of about 10,000 psi at 10^7 cycles. The CMC fiber specimens strength was about 12,000 psi. These specimens were tested to fracture since there was negligible frequency change as a result of cumulative fatigue damage. A rapid frequency change occurs just prior to fracture.

The 0° tension-tension test data are based on complete rupture of the specimens. However, prior to rupture, some specimens experienced edge splintering. This was also the case for the 0° flexural fatigue specimens. This condition was expected because it is impossible to remove specimens from a panel without damaging edge fibers. Since the test data are based upon damaged specimens, the strengths reported are conservative.

In both tension-tension and flexural fatigue tests of 90° oriented fibers, examination of the fracture surfaces showed that the AVCO fiber exhibited more longitudinal splitting than the CMC fiber. This splitting was reflected in slightly lower strength for the AVCO fiber.

Based on a limited sample size for each condition, the panels fabricated with CMC fibers show slightly better axial fatigue strength in both the 0° and 90° specimens and better flexural fatigue strength in the 90° specimens. However, in flexural fatigue, the 0° AVCO fiber specimens were marginally stronger.

3.1.2.4 Impact Tests - Four 2 x 8 in. x 8 ply boron/aluminum plates were ballistic impact tested using Hamilton Standard's air gun facility to determine the relative behavior of CMC and AVCO 8 mil boron/6061 matrix composites under impact loading. The ply layup was ($\pm 45/O_2$)s representing a typical blade layup. The specimens were impacted with 0.625 in diameter gelatin spheres weighing approximately 2.5g. Impact velocity was approximately 860 fps. The impacts were normal to and at the center of the plate. The plates were clamped as cantilever beams six inches from the plate outboard end. The results of the tests are presented in Table 13, Fig. 50 shows the back side of the specimens at the impact site. The results of the impact tests were similar.

3.1.2.4 (Continued)

Specimen 1285A (CMC) refractured completely and specimen 1286A (AVCO) was close to complete fracture. Specimens 1285B and 1286B were also imilar in appearance. All of the specimens experienced extensive gross and local impact site deformation as the result of the impact. No significant differences between CMC and AVCO boron composites were observed.

3.1.3 Fabrication Demonstration

The "Quick Vac" process was demonstrated by the fabrication of an F-100 camber shell with 8 mil AVCO fiber, 6061 matrix and 0.008 mil outer titanium skin. The composite shells on the F-100 1st stage spar shell blade developed for P&WA were fabricated with 9 layers of plasma sprayed 5.7 mil Borsic fibers and 6061 aluminum matrix tape (i.e., borsical), with an 8 mil outer titanium skin. The 5.7 mil fibers were replaced with 8.0 mil fibers for the fabrication demonstrator shells, thus reducing the shell plies to 7 plus an 8 mil outer titanium skin. This results in a 23% reduction in the number of plies and the time required to cut and stack these plies. Fig. 51 shows the shell ply configuration and orientation.

3.1.3.1 Shell Fabrication - The F-100 shell diffusion bonding dies were preheated to 1090°F in a vacuum retort with a vacuum of 10^{-2} to 10^{-3} torr. Upon reaching 1090°F, the electric power and vacuum pump were shut off, the vacuum retort opened immediately, and the seven ply shell with an 8 mil titanium skin placed into the dies as shown in Fig. 52. The vacuum retort door was closed, the power and vacuum turned on immediately, and contact pressure applied to the shell lay-up. When the vacuum reached 2×10^{-1} torr, 5000 ± 500 psi was applied, and by the time the die temperature reached 1050°F the vacuum was at 10^{-2} torr. The cycle from shut down to 1050°F was 5 min., and at this point a cycle of 5000 ± 500 psi, 1050°F, and 10^{-2} torr vacuum was run for 8-10 minutes. The power and vacuum were shut off and the retort was opened immediately, and the shell removed immediately. The shell is shown in Fig. 53. A second shell was processed by the same process parameters.

3.1.3.2 Inspection - Both shells were x-rayed and showed no significant fiber breakages, fiber cross-overs, or misalignment. The second shell was destructively examined and the results showed good compaction and fiber spacing, and no significant fiber breakage as shown in Fig. 54a. Evaluation of the aluminum matrix to the titanium skin, showed no contamination, which was present with air bonded F-100 vane shells during our in-house program. Fig. 54b shows the clean interface between the titanium skin and aluminum matrix.

3.1.4 Summary and Conclusions for Advanced Evaluation

3.1.4.1 Stress Rupture - The 8 mil Boron/6061/AVCO fiber system and the 8 mil Boron/6061/CMC fiber systems behaved similarly with respect to rupture life variation as a function of applied stress. As shown in Fig. 41, for the longitudinal orientation, the CMC system exhibited a generally lower stress rupture strength than the

3.1.4.1 (Continued)

corresponding AVCO system; both systems displayed a rather shallow slope in semi-logarithmic plots of rupture stress as a function of log time. In Fig. 42, it can be observed that both fiber systems exhibited almost identical stress rupture behavior for the transverse direction.

3.1.4.2 Thermal Cycling - The 8 mil Boron/6061/CMC fiber system exhibited modest declines of 5% and 10% for the longitudinal tensile strength and tensile elastic modulus, respectively, after thermal cycling. The tensile strength decline fell within the materials limits of variability.

3.1.4.3 Fatigue - Based on a limited sample size for each condition, the panels fabricated with CMC fibers show slightly better axial fatigue strength in both the 0° and 90° specimens and better flexural fatigue strength in the 90° specimens. However, in flexural fatigue, the 0° AVCO fiber specimens were marginally stronger.

3.1.4.4 Panel Impact - Both the AVCO and CMC fibers with a 6061 matrix showed no significant difference in impact resistance.

3.1.4.5 Fabrication Demonstration - The "Quick Vac" process was successfully demonstrated by the fabrication of an F-100 shell with 8 mil fiber and 6061 matrix and 0.008 mil titanium skin.

3.1.4.6 Fiber Influence - Based on the data, it would appear that 8 mil Boron fibers behaved similarly when incorporated in identical alloy matrix systems. For some properties, i.e., longitudinal stress rupture, the AVCO fiber system was slightly superior, whereas the CMC fiber system was superior for other properties, i.e., fatigue. Therefore, neither system can be depicted as the better fiber. The only exception being that the AVCO fiber evidenced splitting when tensile tested in the transverse direction. A more significant factor than the fiber source appeared to be the alloy matrix used for incorporating the fibers. On the basis of the properties studied, it can be concluded that the 6061 aluminum alloy is a more promising matrix than the 1100 alloy for both the 8 mil and 5.6 mil boron fibers.

3.1.4.7 Bonding Cycles - The "Quick Vac" bonding cycle developed at Hamilton Standard was shown to produce static tensile properties that were equivalent to the properties developed by other bonding methods using different environments, i.e., air bonding or vacuum bonding.

SECTION 4.0 CHARACTERIZATION

4.1 RESULTS AND DISCUSSIONS

For this phase of the work, the most promising system developed in the preceding two phases was selected on the basis of superior mechanical properties and fabrication capability. The 8 mil Boron/6061/AVCO fiber system was approximately equivalent to the 8 mil Boron/6061/CMC fiber system. However, the CMC fiber system showed no indication of fiber splitting in transverse-tensile testing whereas the AVCO fiber system did exhibit such adverse splitting. Therefore, it was decided to use the 8 mil Boron/6061/CMC fiber system for this phase of the program. The particular tapes used for each type of test panel are summarized in Table 14. As shown in this table, all tapes were made from high strength fiber.

4.1.1 Processing

The fabrication procedure used for the preparation of all specimens was the "Quick Vac" bonding method described previously in the general evaluation section for 8 mil Boron/6061/CMC fiber, paragraph 2.3.1.2.3.

4.1.2 Test Program and Results

As indicated in Fig. 6, this program was divided in six stages: static tensile; as fabricated, thermally cycled and 168-hour salt for unidirectional specimens; for blade specimens, static tensile, tension-tension fatigue, creep and stress rupture, stress corrosion, and static in plane shear and modulus.

4.1.2.1 Static Tensile Tests - Longitudinal and transverse unidirectional specimens in the fabricated condition were tensile tested at room temperature and at 450°F. The ultimate tensile strength, modulus and % strain to fracture are presented in Table 15. The data, normalized to 50 V/° of fiber, have been plotted in Figs. 55, 56, 57, and 58.

Neither the room temperature nor the 450°F longitudinal ultimate tensile strength of the as fabricated material was significantly affected by subjection to 1,000 thermal cycles, -65°F to 450°F, or by exposure to 168 hours salt fog. Furthermore testing at 450°F did not cause any strength reduction. The strength properties are considered

4.1.2.1 (Continued)

to be within the realm of experimental error. It should be noted that the longitudinal ultimate tensile properties of these as fabricated specimens were about the same as those of corresponding "Quick Vac" as fabricated specimens in the screening phase, refer to Table 11, at room temperature and particularly at 450°F. With respect to the transverse oriented specimens, all but one of the eight specimens were warped out of shape to such an extent it was impossible to perform a meaningful tensile test. As expected, testing at 450°F caused a marked reduction in strength compared to the room temperature properties. The composite behavior approximated the strength reduction the matrix has been observed to experience when tested at similar elevated temperatures. The room temperature transverse ultimate strength of the as fabricated material was not affected by subjection to thermal cycling or exposure to salt fog. Also, the 450°F transverse ultimate tensile strength of the as fabricated material was not reduced by salt fog exposure. The room temperature and 450°F transverse ultimate tensile strength properties of these as fabricated characterization specimens were in good agreement with the same properties of corresponding "Quick Vac" as fabricated specimens in the screening phase of this program, as seen by reference to Table 11.

The tensile modulus of elasticity for the longitudinal direction was about the same at room temperature and 450°F for all three conditions tested, as shown in Fig. 57.

The tensile modulus of elasticity exhibited somewhat more variability for the transverse orientation than the longitudinal orientation. As shown in Fig. 58, moduli differences as great as 20% occurred between some conditions.

Metallographic examination of the thermally cycled specimens indicated no significant differences in appearance compared to the control specimens that were not thermally cycled. This was expected since no significant strength differences occurred between the control and the thermally cycled longitudinal specimens. Neither matrix softening nor matrix cracking parallel to the fibers or at right angles to the fibers was observed. This was true for the longitudinal specimens and the one transverse specimen that did not warp.

4.1.2.2 Static Tensile Tests: Blade - The blade orientation shell layup consisted of a six ply panel composed of the following elements: a) 10 mil Ti-6Al-4V, b) +45° 8 mil Boron/6061:CMC fiber, c) -45° 8 mil Boron/6061:CMC fiber, d) -45° 8 mil Boron/6061/CMC fiber, e) +45° 8 mil Boron/6061/CMC fiber, and f) 10 mil Ti-6Al-4V.

Axial oriented tensile tests were preformed with blade orientation shell specimen at room temperature and 450°F. The ultimate tensile strength, modulus and % strain to fracture are presented in Table 16. Since this was a blade orientation shell specimen with Ti-6Al-4V cover skins the data have not been normalized to 50 V/° fiber. The tensile specimen used for these tests was the same as used previously. Data plots

4.1.2.2 (Continued)

are presented in Figs 59 and 60 for the average tensile ultimate strength and elastic modulus, respectively. Testing at 450°F resulted in an approximate 13% reduction in strength from the average room temperature value as illustrated in Fig. 59. All of the room temperature and 450°F tensile specimens were examined. The room temperature specimen showed that the fractures occurred from 60° to 90° to the tensile axis, the titanium foils failed along the same planes as the composite, and some longitudinal fiber splitting was evident. The 450°F specimen showed that the fractures occurred from 45° to 60° to the tensile axis, the titanium foils failed along the same planes as the composite, and some fiber splitting was evident. Also, thermal cycling caused ultimate strength reductions both at room temperature and at 450°F. As mentioned earlier, this was not the case with unidirectional material for the longitudinal direction. For the as fabricated condition, the modulus of elasticity declined from its room temperature value about 20% at 450°F. After thermal cycling, the average moduli evinced modest declines at room temperature and 450°F in comparison to the as fabricated material, as shown in Fig. 60.

4.1.2.3 Stress Rupture and Creep Tests: Blade - 450°F stress rupture and creep tests were conducted with blade orientation shell specimens. The creep portion of this work was conducted using Satec Model 881N averaging type electromechanical extensometers with double linear variable differential transducers.

4.1.2.3.1 Test Results - All stress rupture test results are summarized in Table 17. This information was used to plot a stress versus log time curve, Fig. 61. It should be apparent from this curve that the blade shell specimens exhibited go--no go behavior. These specimens either failed immediately on loading, as shown by tests at 68.9, 61.5 and 55 KSI. However, two additional tests at 53.7 and 51.6 KSI have run for 2600 and 3100 hours, respectively without failing to date. Apparently as small a difference as 1300 psi was important to the stress rupture life of this material and made the difference between fracturing or an extended life. 53.7 KSI can be viewed as the 450°F critical rupture stress level, which proved to be about 27% less than the average ultimate tensile strength of this material.

Since stress rupture testing involves the sudden application of the entire load, the specimen does not have any opportunity to adjust to any slight misalignment or bending involved in load application, whereas in tensile testing gradual loading allows some minor adjustment. This may account for the differences in ultimate strength between the tensile test and stress rupture test.

The specimens and conditions for creep testing are summarized in Table 18. It should be noted that initially specimen slippage in the grips was encountered. In order to overcome this problem, the grip end of all but the first few specimens were electroplated with 0.8 mils of sulfamate nickel to provide a good gripping surface. Linear

4.1.2.3.1 (Continued)

plots of elongation as a function of test time are presented in Figs. 62, 63 and 64. These plots can be converted to inches/inch of elongation by dividing by 2.125, the specimen gage length. In consideration of the previous behavior of this material in stress rupture testing, no attempt was made to test at stress levels above 45.4 KSI. Semilogarithmic plots of the elongation versus log of test time are presented in Figs. 65, 66, and 67. As shown, these plots are linear except for the first 5 or 10 minutes of testing, i.e., prior to the attainment of a steady state condition. For each stress level tested, it was possible to characterize each curve by the general equation:

$$\text{elongation} = m \log \text{time} + b \quad (1)$$

Thus, at 450°F, this material exhibited logarithmic creep, which is typical of conventional metals at low temperatures. Theoretical considerations of logarithmic creep usually characterize the process as exhaustion creep behavior. It also was possible to express the elongation for various given periods of creep time as a function of the applied stress in terms of a logarithmic equation:

$$\log E = f(\sigma) \quad (2)$$

A semilogarithmic plot is presented in Fig. 68 for 50 and 100 hour creep periods. In Fig. 69, this plot has been presented in terms of the log % elongation as a function of applied stress. An effort was made without success to correlate m , the slope of the semilogarithmic curve for the equation, $E = m \log(\text{time}) + b$, to the applied stress over the total range of stresses used. Radiographs were taken of the creep specimens at the end of the creep tests, as illustrated in Fig. 70 for BSAd # 1278B-L7 and BSAd # 1277C-L2 subjected to 10.6 KSI and 45.4 KSI respectively. An effort was made to ascertain if there was a significant change in fiber orientation as a result of the specimen undergoing elongation during the creep test. It was observed that the specimen that elongated the most, showed the greatest deviation from the 45° cross ply lay up, i.e., the fibers tended to approach each other so that they were aligned at 43° instead of 45°. Although this general trend was observed, it was not possible to directly correlate change in fiber orientation with elongation experienced. A radiograph of a fractured stress rupture specimen is illustrated in Fig. 71. It can be observed that gross deviation from the initial 45° cross ply orientation occurred almost exclusively at the fracture surface.

4.1.2.4 Stress Corrosion - Stress corrosion tests were conducted by immersing the specimen in a 3.5% NaCl solution and then subjecting it to a specified static load. Five tests were conducted with blade oriented shell specimens that were 0.5 inches wide and 5 inches long. The test results are summarized in Table 19 and illustrated in Fig. 72, a semilogarithmic plot of stress as a function of time to fracture. There are several interesting features to the curve in Fig. 72. First, the applied stress to cause fracture can be expressed as a function of the logarithm of time to fracture.

4.1.2.4 (Continued)

Also, it can be observed that specimens that fractured in as short a time as four hours, did so at stresses some 20,000 psi below the average static room temperature ultimate strength. Visual and metallographic examination indicated that invariably fracture occurred at approximately 45° to the longitudinal specimen axis, i.e., along the fiber orientation. Also, it appeared that very little corrosive attack of the aluminum alloy matrix occurred and no corrosive attack was observed at the Ti-6Al-4V/aluminum alloy interface. The fracture appearance was quite similar to that depicted in Fig. 70.

4.1.2.5 Fatigue Tests - Blade - A typical blade shell orientation of six-ply $\pm 45^\circ$ 8 mil Boron/6061/AVCO fiber with an 8 mil 6Al-4V skin were fabricated by the "Quick Vac" technique discussed in paragraph 2.3.1.2.3, Fig. 45 shows the fatigue test specimen. These specimens were subjected to tension-tension fatigue tests at room temperature and 450°F .

Test Procedure - The specimens were tested in tension-tension at $R = 0.1$ in the Budd Axial Fatigue Machine. The specimens were run at predetermined stress levels to 10^7 cycles or fracture. The stresses were based on P/A values.

Results - The results are shown in Fig. 73. Two room temperature specimens ran out at the 30,000 psi level. One 450°F specimen ran out at 25,000 psi. The elevated temperature run out is about 15% lower than the specimen tested at room temperature. There was no evidence of titanium cover distress prior to rupture.

There was no significant difference in appearance of fracture surfaces to suggest that the modes of fracture were not the same for the two temperature conditions. Clearly, the sample size precludes a realistic evaluation of the effect of the 450°F environment on the fatigue strength of this composite lay up.

4.1.2.6 Static In Plane Shear - A total of eight specimens were manufactured per the drawing shown in Fig. 74. The composite material lay-up was comprised of four layers of Boron/aluminum sandwiched between titanium faces. Four of the specimens had the B/AL oriented in the 0° fiber direction; the remaining specimens had a $\pm 45^\circ$ fiber blade orientation. All specimens were manufactured by the "Quick Vac" process.

Shear loading was induced by loading the ends of the specimens in opposing directions in a Tinius-Olsen machine. Testing was conducted at 70°F and 450°F . Two specimens were subjected to thermal cycling between -65°F and 450°F for 1000 cycles prior to shear loading.

Results - The results of the testing are reported in Table 20. The apparent B/AL composite and titanium shear stresses at specimen maximum stress were obtained from the elastic relationships presented in Fig. 75. The composite moduli were also obtained from the appropriate equation contained in the figure and the known titanium modulus from the literature.

4.1.2.6 (Continued)

Although yielding was accomplished for all eight specimens, fracture of the rail attachments in the form of gross hole elongation and/or bond fracture precluded attainment of ultimate shear stress. Examination of the shear stressing in the titanium indicates values well below the anticipated titanium ultimate shear strength value. Conversely, the B/AL shear stress is well in excess of that anticipated from earlier testing of B/AL formed by the conventional vacuum process. The B/AL therefore yields but is forced through compatibility considerations to follow the deformation in the titanium. Consequently, a continuously increasing percentage of the total load will be acquired by the titanium as the plastic deformation of the composite increases. The stressing obtained from the "elastic" analysis is therefore termed apparent stress. The individual moduli values should be correct since they were obtained from data obtained in the linear range.

4.1.3 Summary and Conclusions

4.1.3.1 Salt Fog Corrosion - Exposure to salt fog corrosion did not diminish the longitudinal ultimate tensile strength and modulus of elasticity at room temperature or 450°F, as shown in Figs. 55 and 57. Also, the transverse ultimate tensile strength at room temperature and 450°F was not reduced by salt fog corrosion, illustrated in Fig. 56. However, the transverse modulus of elasticity at 450°F was about 20% lower than for the as fabricated condition, for no obvious reason.

4.1.3.2. Blade Shell Tensile Properties - The axial ultimate tensile strength and elastic modulus for a ± 45 blade shell configuration, as would be expected, were considerably lower (about 55%) than corresponding values for unidirectional longitudinal material. At 450°F, the ultimate tensile strength dropped about 13% compared to its average room temperature counterpart and the modulus declined 20% at 450°F. Thermal cycling caused ultimate strength reductions at both room temperature and 450°F of 9% and 14% respectively, whereas the average moduli experienced declines at room temperature of 9% and at 450°F of 3%.

4.1.3.3 Tension-Tension Fatigue - The results of this investigation showed that there was no significant difference in fatigue strength between room temperature and 450°F.

4.1.3.4 Creep & Stress Rupture

4.1.3.4.1 Stress Rupture - As shown in Fig. 61, the axial stress rupture data for the blade shell material was quite limited. However, based on the number of points available, it was possible to construct a semilogarithmic plot of applied stress vs. log time. This curve exhibited a very shallow slope and the apparent critical stress rupture level of 53.7 KSI was approximately 65% to 70% less than that for unidirectional longitudinal material.

4.1.3.4.2 Creep - The creep data could be expressed in several ways: elongation as a function of the log time and the log of elongation as a function of applied stress. Typical plots are shown in Figs. 65 through 69. In general, at 450°F this material exhibited logarithmic creep.

4.1.3.5 In Plane Shear - It is concluded from this evaluation that ultimate shear strengths in excess of 24 to 36 KSI are available for this B/AL-Ti composite material manufactured by the "Quick Vac" process. Elevated temperature and thermal cycling exposure do not appear to effect a gross strength degradation based on the data available from this testing.

TABLE 1
TAPE DATA FOR 8 MIL BORON/6061/CMC FIBER SYSTEM

Tape #	Tape Source	Tape Dens. gr/in ²	Fiber ends/in	Calc. Fiber V/°	As Rec.	Extracted Fiber, UTS					Panel #
					Fiber From Spool, UTS	Tape		Panel			
					X10	X10	σ	X10	σ		
8.0-6061-2M-3	CMC	0.375	102	57.1	502	422	33	569	73	1147	
					502			518	79	1149	
					557			543	78	1150	
								556	64	1151	
2873-55	UCAR	0.357	90.6	52.8	545	235	21	454	44	1165	
					488			375	65	1166	
					450			342	58	1167	
								361	58	1168	
							408	73	1169		
2873-73	UCAR	0.379	92.7	50.7	450	215	40	---		----	
					503						
2873-74	UCAR	0.374	92.7	51.6	---	222	16	---		----	
2873-76	UCAR	0.377	92.7	50.6	585	208	27	397	62	1181	
								438	59	1188	
2873-77	UCAR	0.377	92.7	51.1	569	218	25	439	55	1178	
								449	57	1180	
2922-86	UCAR	0.371	92.7	51.9	605	-	-	-	-	1233	

Note: X = mean of 10 specimen
σ = Std. deviation

TABLE 2
PANEL STRENGTH PROPERTIES FOR THE 8 MIL BORON/6061/CMC FIBER SYSTEM

Panel Specimen #	* Tape Source	Tape Number ⁽¹⁾	Fab. Atm.	Press. KSI	Peak Temp. °F	Peak Time Min.	Cycle ⁽²⁾	Fiber Orient.	Fiber V°	U. T. S. KSI	Normalized to 50V/° Fiber U. T. S. (3) KSI
1151-L1	CMC	8.0-6061-2M-3	Air	6	996	9.5	B	C	49.1	165	168
									49.8	232	233
									49.6	207	209
									49.5	232	234
1151-T1								90	48.8	16.1	16.5
1151-T2								90	49.2	15.9	16.2
1152-L1	CMC	8.0-6061-2M-3	Air	6	1000	12	C	0	49.9	169	169
								0	49.5	170	172
1152-T1								90	49.2	17.5	17.8
1152-T2								90	49.6	20.9	21.1
1153-L1	CMC	8.0-6061-2M-3	Air	6	1015	10	C	0	50.2	166	166
1153-L2								0	50.9	162	162
1153-T1								90	49.6	11.9	12.0
1153-T2								90	49.6	24.6	24.8
1153-T3								90	49.6	24.7	24.8
1154-L1	CMC	8.0-6061-2M-3	Air	6	986	10	C	0	49.9	170	170
1154-L2								0	49.5	202	204
1154-L3								0	48.7	233	239
1154-T1								90	48.3	12.4	12.8
1154-T2								90	49.2	14.9	15.1
1154-T3								90	49.5	15.1	15.3
1164-L1	CMC	8.0-6061-2M-3	Air	6	1030	1.5	C	0	51.3	252	246
1164-L2								0	51.1	170	166
1164-L3								0	49.6	183	184

* 1 mil aluminum foil placed between plys on all CMC tape

TABLE 2 (Continued)

Panel Specimen #	* Tape Source	Tape Number ⁽¹⁾	Fab. Atm.	Press. KSI	Peak Temp. °F	Peak Time Min.	Cycle ⁽²⁾	Fiber Orient.	Fiber V/°	U. T. S. KSI	Normalized to 50V/° Fiber U. T. S. (3) KSI
1164-T1	UCAR	2873-55	Air	5	1010	8	C	90	50.0	12.1	12.1
1164-T2								90	49.8	11.9	11.9
1164-T3								90	48.3	10.7	11.1
1166-L1								0	46.5	190	204
1166-L2								0	46.2	184	199
1166-L3								0	45.8	186	203
1166-L4								0	45.9	178	194
1166-T1								90	45.9	13.8	15.0
1166-T2								90	46.0	14.2	15.4
1166-T3								90	46.0	14.8	16.1
1146-L1	CMC	8.0-6061-2M-3	Fac.	5	1005	5	F	0	53.7	192	179
1146-T1								90	53.8	17.2	16.0
1146-T2								90	53.6	14.0	13.1
1147-L1								0	53.9	225	209
1147-L2								0	53.7	193	180
1147-T1								90	54.3	18.7	17.2
1147-T2								90	53.7	17.7	16.5
1147-T3								90	53.9	16.7	15.5
1148-L1	CMC	8.0-6061-2M-3	Vac.	6	1023	13	F	0	49.5	170	172
1148-T1								90	50.3	19.9	19.8
1148-T2								90	50.0	19.8	19.8
1149-L1								0	48.8	194	199
1149-L2								0	48.9	188	192
1149-T1	CMC	8.0-6061-2M-3	Vac.	6	1003	11	F	90	49.8	18.4	18.6
1149-T2								90	49.2	20.6	20.9
1149-T3								90	49.6	19.4	19.6

TABLE 2 (Continued)

Panel Specimen #	* Tape Source	Tape Number ⁽¹⁾	Fab. Atm.	Press. KSI	Peak Temp. °F	Peak Time Min.	Cycle ⁽²⁾	Fiber Orient.	Fiber V/°	U. T. S. KSI	Normalized to 50V/° Fiber U. T. S. (3) KSI
1169-L1	UCAR	2873-55	Vac.	5	915	26	F	0	50.5	213	211
1169-L2								0	50.5	222	220
1169-L3								0	50.4	210	208
1169-L4								0	50.6	225	222
1169-T1								90	50.2	18.3	18.2
1169-T2								90	49.9	15.0	15.0
1169-T3								90	50.3	17.1	17.0
1173-T1	CMC	8.0-6061-2M-3	Vac.	5	915	26	F	90	52.1	16.3	15.6
1173-T2								90	53.0	16.7	15.8
1173-T3								90	53.7	16.6	15.5
1167-L1	UCAR	2873-55	Air	5	998	10	C	0	46.3	159	172
1167-L2								0	45.5	191	210
1167-L3								0	45.1	189	208
1167-L4								0	45.3	171	189
1167-T1								90	45.6	14.2	15.6
1167-T2								90	46.3	14.6	15.8
1167-T3								90	45.8	12.6	13.8
1168-L1	UCAR	2873-55	Air	5	1000	10	C	0	51.9	194	186
1168-L2								0	50.6	216	213
1168-L3								0	50.7	208	205
1168-L4								0	50.6	207	204
1168-L5								0	50.5	216	214
1168-T1								90	50.3	17.1	16.9
1168-T2								90	50.5	13.2	13.1
1168-T3								90	50.0	12.6	12.6
1168-T4								90	50.2	20.1	19.9

TABLE 2 (Continued)

Panel Specimen #	Tape Source	Tape Number(1)	Fab. Atm.	Press. KSI	Peak Temp. °F	Peak Time Min.	Cycle(2)	Fiber Orient.	Fiber V/°	U. T. S. KSI	Normalized to 50V/° Fiber U. T. S. (3) KSI
1176-L1	UCAR	2873-77	Air	5	1010	4.5	D	0	50.6	195	193
1176-L2								0	49.5	203	205
1176-L3								0	48.4	191	197
1176-T1								90	49.0	17.8	18.2
1176-T2								90	49.0	20.6	21.0
1176-T3								90	49.3	15.0	15.2
1177-L1	UCAR	2873-77	Air	5	998	14	D	0	48.1	198	206
1177-L2								0	48.1	154	160
1177-T1								90	47.9	16.4	17.1
1177-T2								90	48.1	20.6	21.4
1177-T3								90	48.1	17.2	17.9
1177-T4								90	48.1	15.8	16.4
1178-L1	UCAR	2873-77	Air	5	1010	9.5	D	0	50.2	167	166
1178-L2								0	49.2	199	202
1178-T1								90	48.8	14.3	14.6
1178-T2								90	49.0	20.8	21.2
1178-T3								90	49.0	22.8	23.2
1180-L1	UCAR	2873-77	Air	5	1003	10	D	0	49.2	199	203
1180-L2								0	49.2	202	206
1180-T1								90	49.0	19.5	19.9
1180-T2								90	49.0	24.5	24.9
1181-L1	UCAR	2873-76	Air	5	1006	10.5	D	0	48.7	194	199
1181-L2								0	48.5	180	182
1181-T1								90	49.0	17.7	18.1
1181-T2								90	49.1	18.1	18.4

TABLE 2 (Continued)

Panel Specimen #	Tape Source	Tape Number ⁽¹⁾	Fab. Atm.	Press. KSI	Peak Temp. °F	Peak Time Min.	Cycle ⁽²⁾	Fiber Orient.	Fiber V/°	U. T. S. KSI	Normalized to 50V/° Fiber U. T. S. (3) KSI
1188-L1	UCAR	2873-76	Air	5	1004	11	E	0	49.6	162	163
1188-L2								0	49.3	210	213
1188-L3								0	48.9	205	210
1188-T1								90	49.0	11.9	12.2
1188-T2								90	49.0	25.5	26.1
1188-T3								90	48.9	19.6	20.1
1198-L1	UCAR	2873-76	Air	5	1027	4	E	0	48.0	167	174
1198-L2								0	48.2	194	201
1199R-L1	UCAR	2873-74	Air	5	1005	10	E	0	48.4	189	195
1199R-T2								90	46.2	10.9	11.9
1200-L1	UCAR	2873-73	Air	5	1004	10	E	0	47.0	192	205
1200-L2								0	46.2	183	199
1233-L1	UCAR	2922-86	Air	5	1010	10	E	0	49.6	186	187
1233-L2								0	49.6	212	213
1233-L3								0	49.6	208	209

FOOTNOTES TO TABLE 2

- (1) See Table 1 for tape properties.
- (2) Cycle A did not result in a fully compacted panel, so data from this panel was not included in the tabulation. Steps in Cycle A were:

- (a) Insert layup between preheated platens.
- (b) Immediately apply full compaction pressure. Maintain through intended time at peak temperature.
- (c) Heat to peak temperature and hold at this temperature for specified time.
- (d) Separate platens and remove panel immediately.
- (e) Cool panel rapidly using steel plates and compressed air jet.

Cycle B:

- (a) Insert layup between preheated platens.
- (b) Under contact pressure of 100-200 psi, heat layup to peak temperature.
- (c) Immediately apply full compaction pressure. Maintain through intended time at peak temperature.
- (d) Hold at peak temperature for specified time.
- (e) & (F) Same as for Cycle A, (d) and (e).

Cycle C:

- (a) Insert layup between preheated platens.
- (b) Under contact pressure of 100-200 psi, heat layup to 920°F.
- (c) Apply full compaction pressure. Maintain through intended time at peak temperature.
- (d) Heat to peak temperature and hold for specified time.
- (e) & (f) Same as for Cycle A, (d) and (e).

Cycle D:

- (a) & (b) Same as Cycle C.
- (c) Apply compaction pressure in 1000 psi increments to 5000 psi with 30 second dwell times between each incremental increase.
- (d), (e) & (f) Same as Cycle C.

FOOTNOTES (Continued)

Cycle E:

(a) & (b) Same as Cycle C.

(c) Apply compaction pressure of 3000 psi at 940°F to 950°F, dwell for one minute, apply additional 1500 psi, dwell for one minute, apply additional 1000 psi.

(d), (e) & (f) Same as Cycle C.

Cycle F:

(a) Position layup between platens and close up system.

(b) Pump system down to 10^{-4} Torr or better.

(c) Heat at 500°F/hour to peak temperature.

(d) Apply full compaction pressure. Maintain for rest of cycle.

(e) Hold at peak temperature for intended time.

(f) Cool from peak temperature to room temperature at 400°F/hour.

(3) Average Strength Values:

	Fiber Orient.	No. of Tests	U. T. S. Normal Red To 50% Fiber Value	
			\bar{X} KSI	σ KSI
A. Air Panels	0	49	196	20.5
	90	41	17.2	4.05
B. Vacuum Panels	0	10	199	17.7
	90	16	17.1	2.16

TABLE 2A
PANEL STRENGTH PROPERTIES FOR THE 8 MIL BORON/6061 CMC FIBER SYSTEM
450°F

Panel Specimen #		Tape Source	Orient.	V/°	U. T. S. KSI	Normalized to 50V/° Fiber U. T. S. KSI	Modulus PSI x 10 ⁶	% In. /In.
2873-77	{1180-LH1	UCAR	0	49.0	160.8	164.1	32.8	0.56
	{1180-LH2	UCAR	0	48.2	133.0	138.0	---	0.45
2875-76	{1181-LH1	UCAR	0	48.4	155.7	160.0	37.9	0.52
	{1181-LH2	UCAR	0	48.4	156.6	161.8	32.7	0.54
2873-77	{1178-LH1	UCAR	0	49.0	174.0	177.6	31.5	0.63
	{1178-LH2	UCAR	0	49.0	168.0	165.3	---	---
	{1178-LH3	UCAR	0	49.5	197.5	199.5	37.3	0.60
	{1178-LH4	UCAR	0	48.9	167.3	171.1	30.3	0.61
2922-99	{1281A-1 (1)	UCAR	90	50.2	17.6	17.5	16.2	0.32
	{1281A-2 (2)	UCAR	90	48.9	17.1	17.7	23.5	0.44
	{1281A-3 (1)	UCAR	90	50.2	17.1	17.0	19.5	0.34
	{1281A-4 (1)	UCAR	90	51.5	18.6	18.2	19.1	0.42

(1) "Quik-Vac" bonded per paragraph 2.3.1.2.3

Tape # 2922-99; Fibers: 11-2708, 16-5107. Tape #2873-77; Fibers: 10-834

Fiber Dia: 7.90 & 8.0 Mils, Spacing: 92.7/In.

Fiber Dia: 8.0 Mils, Spacing: 92.7/In.

Tape #2873-76; Fibers: 14A-362.

Fiber Dia: 7.95 Mils, Spacing: 92.7/In.

TABLE 3
DEGRADATION AND RECOVERY OF STRENGTH OF PLASMA SPRAYED FIBER

<u>Specimen Number</u>	<u>Condition**</u>	<u>T-1632 AVC/6061</u>	<u>T-1634 AVC/1100</u>	<u>T-1637 CMC/6061</u>	<u>T-1633 CMC/1100</u>
A-1	Unsprayed	575/44	525/162	539/65	524/59
-2	As Sprayed	394/49	396/68	245/30	264/22
-3	450°C - 2 min	483/38	492/85	306/35	366/39
-5	450°C - 10 min	540/46	512/79	341/48	408/31
-7	450°C - 40 min	518/53	539/100	422/59	448/47
B-1	Unsprayed	579/48	514/101	518/74	527/65
-2	As Sprayed	358/50	334/70	262/42	281/19
-3	500°C - 2 min	493/66	524/72	397/55	429/59
-5	500°C - 5 min	522/65	529/96	429/64	451/80
-7	500°C - 10 min	536/64	539/93	425/34	485/67
-9	500°C - 20 min	552/69	511/109	567/63	596/68
-11	500°C - 40 min	575/90	490/91	513/75	489/69
C-1	Unsprayed	606/74	476/64	547/48	465/98
-2	As Sprayed	363/62	440/51	238/28	263/41
-3	550°C - 2 min	579/56	519/85	532/52	476/81
-5	550°C - 5 min	469/70	464/63	527/72	491/53
-7	550°C - 10 min	646/80	475/110	552/41	484/59
-9	550°C - 20 min	611/107	447/121	460/69	449/87
-11	550°C - 40 min	584/41	442/55	437/50	432/76

* 20 fiber tests each

** All hot pressed in air at 5000 psi pressure

*** UTS/STD dev.

TABLE 4
FIBER TRACEABILITY, AVERAGE ULTIMATE TENSILE STRENGTH

<u>System</u>	<u>Identity</u>	<u>Vendor Spool Data</u>		<u>Q. C. Spool Check (1)</u>		<u>Panel Extracted</u>	
		<u>Dia. Mils</u>	<u>U. T. S. in KSI</u>	<u>U. T. S.</u>	<u>Std. Dev.</u>	<u>Fiber Data (1)</u>	
1100/8 Mil B/1100 AVCO Fiber	Spool #25B-68	8.00	510	508	64		
	Spool #27B-8H	8.00	520	501	113		
	Spool #27B-57	7.90	495	578	53		
	Panel #1212					445	74
	Panel #1214					423	75
1100/8 Mil B/1100 CMC Fiber	Spool #14A-890	8.05	519	513	33		
	Spool #14A-880	8.00	476	510	37		
	Spool #14A-879	8.10	597	480	79		
	Spool #14A-864	8.05	594	516	75		
	Panel #1209					361	64
	Panel #1210					391	91
6061/8 Mil B/6061 AVCO Fiber	Spool #27B-73	7.90	485	478	64		
	Spool #27B-79B	7.90	470	587	86		
	Spool #27B-79M	7.90	470	600	96		
	Spool #27B-40	7.90	470	582	62		
	Panel #1215					517	67
	Panel #1217					517	75
1100/5.6 Mil B/1100 CMC Fiber	Spool #14A-865	5.60	450 min	538	49		
	Spool #14A-866	5.70	450 min	556	53		
	Panel #1224					421	61
	Panel #1226					403	41
5051/5.6 Mil B/6061 CMC Fiber	Spool #6-2654	5.65	589	567	59		
	Spool #14A-867	5.55	450 min	562	27		
	Panel #1220					486	60
	Panel #1221					523	40

(1) U. T. S. is in KSI for an \bar{X} value, based on N = 20 tests.

TABLE 5
PANEL STRENGTH PROPERTIES FOR THE 8 MIL BORON/6061/AVCO FIBER SYSTEM;

6061/8 MIL B/6061/ AVCO FIBER

# Specimen	<u>Orient.</u>	<u>V/°</u>	<u>U. T. S. KSI</u>	<u>Normalized to 50V/° Fiber U. T. S. KSI</u>	<u>Modulus PSI x 10⁶</u>	<u>% In/In.</u>
<u>R. T. Tensile</u>						
1215-L1	0	50.4	140.1	139.0	33.9	0.47
1215-L2	0	49.7	225.5	226.9	34.8	0.74
1215-L3	0	49.8	206.4	207.2	34.6	0.65
1215-L4	0	49.7	225.0	226.4	35.7	0.70
1215-T1	90	49.3	20.0	20.3	18.8	0.16
1215-T2	90	49.7	20.7	20.8	20.9	0.33
1215-T3	90	49.4	21.4	21.6	19.6	0.29
1215-T4	90	50.1	24.9	24.8	23.5	0.37

450°F Tensile

1215-LH1	0	49.6	182.7	184.1	33.3	0.64
1215-LH2	0	49.8	169.4	170.0	32.5	0.57
1215-LH3	0	49.8	197.4	198.2	37.6	0.64
1216-LH1	0	49.8	182.8	183.5	34.3	0.65
1217-TH1	90	49.5	14.2	14.3	19.1	0.38
1217-TH2	90	49.4	14.9	15.1	17.9	0.28
1217-TH3	90	49.4	13.3	13.5	-	-
1217-TH4	90	49.4	12.9	13.1	17.9	0.17

R. T. Impact

# Specimen	<u>Orient.</u>	<u>V/°</u>	<u>Ft-Lb/In.²</u>	<u>P Max. Lbs.</u>	<u>Bend KSI</u>	<u>Ft-Lb</u>
1215-I1	0	49.4	27.7	144.9	280.0	0.62
1215-I2	0	49.7	31.5	149.2	280.9	0.71
1215-I3	0	50.5	29.3	133.2	268.4	0.63
1215-I4	0	49.9	32.2	138.6	281.2	0.69
1215-I5	0	49.4	28.5	138.6	264.7	0.74
1217-1	90	49.4		---		0.25
1217-2	90	49.1		---		0.18
1218-3	90	49.6		---		0.45
1217-4	90	48.7		---		0.35
1216-1	90	48.9				0.28

Shear at Prop. Limit
(ksi)

9.64
9.64

Tape #2922-21; Fibers: 25B-73, 27B-79, 25B-40. X-Ray #1215, 1217.
Fiber Data: 7.90 Mils, Spacing: 93/In.

TABLE 6
PANEL STRENGTH PROPERTIES FOR THE 8 MIL BORON/1100/REVISED AVCO FIBER SYSTEM;
"STANDARDIZED" PROCESSING

1100/8 Mil B/1100/ AVCO Fiber

# Specimen	<u>Orient.</u>	<u>V/°</u>	<u>U. T. S. KSI</u>	<u>Normalized to 50V/° Fiber U. T. S. KSI</u>	<u>Modulus PSI x 10⁶</u>	<u>% In./In.</u>
<u>R. T. Tensile</u>						
1212-L1	0	50.4	176.2	174.8	28.4	0.52
1212-L2	0	49.6	181.8	183.3	28.5	0.66
1213-L1	0	49.5	183.0	184.8	28.7	0.65
1213-L2	0	48.9	180.0	184.0	30.6	0.50
1212-T1	90	48.0	---	---	---	---
1213-T2	90	49.2	6.2	6.3	---	0.06
1213-T3	90	49.7	7.8	7.8	16.9	0.03
1213-T4	90	48.4	7.1	7.1	12.9	0.06

450° F Tensile

1212-LH1	0	49.4	133.5	133.8	32.5	0.46
1212-LH2	0	48.9	137.9	141.0	---	---
1213-LH1	0	48.9	121.2	123.9	---	---
1213-LH2	0	49.9	130.4	130.7	33.4	0.47
1214-TH1	90	48.9	---	---	---	---
1214-TH2	90	49.6	6.9	7.0	---	---
1214-TH3	90	48.7	2.8	2.9	13.8	0.02
1214-TH4	90	49.2	5.1	5.2	7.7	0.12

R. T. Impact

# Specimen	<u>Orient.</u>	<u>V/°</u>	<u>Ft-Lb/In.²</u>	<u>P Max Lbs</u>	<u>Bend KSI</u>	<u>Ft-Lb</u>
1212-I1	0	50.1	20.6	123.7	227.6	0.47
1212-I2	0	49.7	30.1	153.5	286.0	0.68
1212-I3	0	49.1	20.8	123.7	235.7	0.46
1212-I4	0	48.7	23.0	132.2	250.7	0.51
1213-LI1	0	47.6	34.1	149.2	274.7	0.78
1214-TI1	90	49.8	---	---	---	0.06
1214-TI2	90	48.3	---	---	---	0.04
1214-TI3	90	49.3	---	---	---	0.04
1214-TI4	90	48.3	---	---	---	0.06
1214-TI5	90	48.7	---	---	---	0.05

Shear at Prop. Limit
(ksi)

2.9

Tape # 2922-27; Fibers: 25B-68, 27B-8H, 27B-57. X-Ray #1213, 1214.
Fiber Dia: 8.0 Mils, Spacing: 92.7/In.

TABLE 6A
PANEL STRENGTH PROPERTIES FOR THE 8 MIL BORON/1100/
AVCO FIBER SYSTEM; SPECIAL PROCESSING

1100/8 Mil B/1100/ AVCO Fiber

<u>#</u> <u>Specimen</u>	<u>Orient.</u>	<u>V/°</u>	<u>U. T. S.</u> <u>KSI</u>	<u>Normalized</u> <u>to 50V/° Fiber</u> <u>U. T. S. KSI</u>	<u>Modulus</u> <u>PSI x 10⁶</u>	<u>% In./In.</u>
<u>R. T. Tensile</u>						
1218-L2	0	48.5	165.0	170.1	35.8	0.52
1219-L1	0	48.7	Broken on Load			
1218-T1	90	48.1	Broken on Load			
1218-T2	90	48.7	7.2	7.5	17.3	0.08
1218-T3	90	48.4	7.2	7.3	20.8	0.06
1218-T9	90	49.3	8.9	9.0	22.3	0.14

450°F Tensile

1218-LH1	0	49.0	132.7	135.4	29.4	0.49
1218-TH1	90	48.8	7.5	7.7	12.7	0.14
1218-TH2	90	49.1	7.3	7.4	16.9	0.15

R. T. Impact

<u>#</u> <u>Specimen</u>	<u>Orient.</u>	<u>V/°</u>	<u>Ft-Lbs/In.²</u>	<u>P max</u> <u>Lbs</u>	<u>Bend</u> <u>KSI</u>	<u>Ft-Lb</u>
1218-TI1	90	49.0				0.125
1218-TI2	90	48.9	---			0.08
1218-TI3	90	49.3	---			0.08
1218-TI4	90	48.7	---			0.07

Tape # 2922-28; Fibers:

Fiber Dia: 7.9 Mils, Spacing: 92.7/In.

TABLE 7
PANEL STRENGTH PROPERTIES FOR THE 8 MIL BORON/1100/CMC FIBER SYSTEM

1100/8 Mil B/ 1100/ CMC Fiber

# Specimen	<u>Orient.</u>	<u>V/°</u>	<u>U. T. S. KSI</u>	<u>Normalized to 50V/° Fiber U. T. S. KSI</u>	<u>Modulus PSI x 10⁶</u>	<u>% In./In.</u>
<u>R. T. Tensile</u>						
1209-L1	0	49.0	150.9	154.6	---	0.47
1209-L2	0	48.4	172.0	179.7	32.9	0.62
1211-L1	0	48.5	154.0	158.8	32.9	0.54
1211-L2	0	48.4	164.0	169.4	30.0	0.58
1209-T1	90	49.5	6.6	6.7	11.2	0.10
1209-T2	90	49.5	---	---	---	---
1209-T3	90	49.9	9.6	9.6	17.6	0.08
1209-T4	90	50.1	7.5	7.5	17.6	0.06

450° F Tensile

1211-LH1	0	49.3	---	---	---	---
1211-LH2	0	48.4	---	---	---	---
1211-LH3	0	48.6	87.4	89.9	---	0.28
1211-LH4	0	48.5	125.0	128.9	31.0	0.46
1210-TH1	90	48.6	5.1	5.2	---	---
1210-TH2	90	49.1	4.1	4.2	---	---
1210-TH3	90	48.6	6.7	6.9	---	---
1210-TH4	90	48.8	4.8	4.8	---	---

R. T. Impact

# Specimen	<u>Orient.</u>	<u>V/°</u>	<u>Ft-Lbs/In.²</u>	<u>P Max Lbs</u>	<u>Bend KSI</u>	<u>Ft-Lb</u>
1209-I1	0	47.7	25.7	117.3	199.0	0.60
1209-I2	0	49.0	23.2	113.0	207.9	0.52
1209-I3	0	49.6	23.2	123.7	215.9	0.54
1209-I4	0	49.4	25.0	132.2	235.4	0.58
1209-I5	0	50.1	23.5	123.7	235.1	0.52
1210-1	90	48.8	---	---	---	0.05
1210-2	90	48.5	---	---	---	0.05
1210-3	90	48.8	---	---	---	0.07
1210-4	90	48.4	---	---	---	0.08
1210-5	90	48.8	---	---	---	0.06

Shear at Prop. Limit
(ksi)

2.66
4.43

Tape # 2922-12; Fibers: 14A-890, 14A-880, 14A-879. X-Ray = 1210, 1211.
Fiber Dia.: 8.05; Spacing: 92.7/In.

TABLE 8
PANEL STRENGTH PROPERTIES FOR THE 5.6 MIL BORON/6061/CMC FIBER SYSTEM

6061/5.6 Mil B/6061/ CMC Fiber

<u>#</u> <u>Specimen</u>	<u>Orient</u>	<u>V/°</u>	<u>U. T. S.</u> <u>KSI</u>	<u>Normalized</u> <u>to 50V/° Fiber</u> <u>U. T. S. KSI</u>	<u>Modulus</u> <u>PSI x 10⁶</u>	<u>% In./In.</u>
<u>R. T. Tensile</u>						
1210R-L1	0	55.1	240.8	218.5	39.21	0.69
1219R-L2	0	54.8	285.0	260.0	38.40	0.81
1219R-L3	0	54.4	266.2	244.7	37.92	0.77
1219R-L4	0	53.8	232.7	216.3	39.21	0.72
1220-T1	90	54.5	25.6	23.5	26.94	0.49
1220-T2	90	54.8	27.4	25.0	26.75	0.46
1220-T3	90	54.0	30.9	28.6	28.14	0.76
1220-T4	90	54.4	26.8	24.6	27.38	0.35

450°F Tensile

1219R-LH1	0	53.3	133.0	122.9	---	---
1219R-LH2	0	52.4	183.0	174.6	---	---
1210R-LH3	0	53.1	218.0	205.3	33.94	0.70
1221-LH1	0	---	229.1	216.0	39.58	0.70
1220-TH1	90	54.3	15.0	13.8	16.5	0.49
1220-TH2	90	54.9	17.6	16.0	17.2	0.48
1220-TH3	90	54.5	18.9	17.3	20.4	0.33
1220-TH4	90	54.9	16.7	15.2	17.5	0.34

R. T. Impact

<u>#</u> <u>Specimen</u>	<u>Orient.</u>	<u>V/°</u>	<u>Ft-Lbs/In.²</u>	<u>P Max</u> <u>Lbs</u>	<u>Bend</u> <u>KSI</u>	<u>Ft-Lb</u>
1219R-I1	0	53.8	26.1	115.0	266.4	0.53
1219R-I2	0	55.0	31.7	140.0	236.2	0.63
1219R-I3	0	55.1	23.6	115.0	282.9	0.46
1219R-I4	0	54.6	27.9	180.0	421.6	0.56
1221-I1	0	54.9	29.4	125.0	299.8	0.59
1220-1	90	54.4	15.3	16.0	37.4	0.31
1220-2	90	55.2	13.5	24.0	57.8	0.27
1220-3	90	54.5	12.2	20.0	45.4	0.25
1220-4	90	55.1	16.2	22.0	53.3	0.32
1219R-1	90	55.0	18.3	20.0	47.7	0.37

Shear At Prop. Limit
(ksi)

6.54
6.03

Tape # 2922-20; Fibers: 6-2654, 14A-867
Fiber Dia: 5.60 Mils, Spacing: 139.4/In.

TABLE 9
PANEL STRENGTH PROPERTIES FOR THE 5.6 MIL BORON/1100/CMC FIBER SYSTEM

1100/5.6 Mil B/1100/ CMC Fiber

# Specimen	Orient.	V/°	U. T. S. KSI	Normalized to 40V/° Fiber U. T. S. KSI	Modulus PSI x 10 ⁶	% In./In.
<u>R. T. Tensile</u>						
1224-L1	0	53.6	167.8	156.5	38.36	0.50
1224-L2	0	53.4	170.2	159.4	36.79	0.50
1224-L3	0	53.8	145.4	135.1	36.08	0.44
1224-L4	0	52.7	183.9	174.5	44.75	0.57
1225-T1	90	53.3	6.5	6.1	16.13	0.15
1225-T2	90	53.4	6.6	6.2	13.63	0.08
1225-T3	90	53.6	7.3	6.8	13.58	0.15
1225-T4	90	43.7	6.5	6.1	14.79	0.07

450°F Tensile

1224-LH1	0	52.9	>162.0	160.0	---	---
1224-LH2	0	52.7	>176.0	170.0	---	---
1224-LH3	0	52.4	---	---	---	---
1226-LH1	0	53.7	---	---	---	---
1225-TH1	90	53.0	---			---
1225-TH2	90	53.4	---			
1225-TH3	90	53.0	---			
1226-TH1	90	53.0	---			
1226-TH2	90	53.0	3.8	3.6	14.42	0.07

R. T. Impact

# Specimen	Orient.	V/°	Ft-Lbs/In. ²	P Max Lbs	Bend KSI	Ft-Lb
1224-I1	0	52.4	22.3	105.0	244.4	0.44
1224-I2	0	52.7	14.4	85.0	204.2	0.28
1224-I3	0	52.8	20.0	95.0	255.4	0.35
1224-I4	0	52.7	14.4	85.0	211.5	0.29
1225-I1	0	54.6	14.9	90.0	100.8	0.31
1224-1	90	55.1				0.08
1225-1	90	53.4				0.05
1225-2	90	53.3				0.04
1225-3	90	53.2				0.06
1225-4	90	53.1				0.05

Shear at Prop. Limit
(ksi)

5.17

Tape #2992-16; Fibers: 14A-865, 14A-866, 14A-867
Fiber Dia: 5.65 Mil Spacing: 139.4/In.

TABLE 10
THIN PLATE IMPACT

<u>SYSTEM</u>	<u>T</u>	<u>B</u>	<u>B/T</u>	<u>E1</u>	<u>E</u>	<u>E1/E</u>
Matrix/Fiber Source	Avg 30° UTS 10 PSI	Avg. 0° Bend Strength 10 ³ PSI		(B ² /18E) In. - Lbs/In. ³	Energy/ Vol In. lbs/In. ³	
1100/8 Mil CMC	160.2	218.7	1.36	78	183.0	0.43
1100/8 Mil AVCO	180.2	254.9	1.41	124	227.0	0.55
1100/8 Mil AVCO	137.2	---	---	---	---	---
1100/5.6 Mil CMC	166.8	223.3	1.34	71	130.7	0.54
6061/8 Mil CMC	151.5	---	---	---	---	---
6061/8 Mil AVCO	199.3	276.6	1.39	122	226.0	0.54
6061/5.6 Mil CMC	256.2	301.4	1.18	130	210.0	0.62

TABLE 11
SUMMARY OF THE AVERAGE STATIC TENSILE MECHANICAL PROPERTIES
OF THE SCREENING PHASE COMPOSITE SYSTEMS

System	Fiber Orientation	Test °F	U. T. S. Normalized to 50 V/° Fiber	σ ksi	ε T % In./In.	Average Tensile Modulus PSI x 10 ⁶	Preparation
8 mil B/6061/CMC Fiber	0°	R. T.	10	199.0	17.7		Vacuum Bonding
	90°	R. T.	16	17.1	2.16		Vacuum Bonding
	0°	R. T.	49	196.0	20.5	3	Air Bonding
	90°	R. T.	41	17.2	4.05	2	Air Bonding
	0°	R. T.	4	202.0		3	"Quik-Vac"
	90°	R. T.	4	24.9	2.20	3	"Quik-Vac"
	0°	450	8	178.0	15.0	6	"Quik-Vac"
	90°	450	4	17.6	0.5	4	"Quik-Vac"
	0°	R. T.	4	200.0	41.6	4	Air Bonding
	90°	R. T.	4	21.9	2.0	4	Air Bonding
8 mil B/6061/AVCO Fiber	0°	450	4	184.0	11.5	4	Air Bonding
	90°	450	4	14.0	0.9	4	Air Bonding
	0°	R. T.	4	182.0	4.7	4	Air Bonding: Standardized
	90°	R. T.	4	7.1	1.2	2	Air Bonding: Standardized
	0°	R. T.	1	170.0	---	1	Air Bonding: High Peak
	90°	R. T.	3	7.9	1.8	3	Temp
	0°	450	4	132.0	7.1	2	Air Bonding: High Peak
	90°	450	3	5.0	2.1	2	Temp
	0°	450	1	135.0	---	1	Air Bonding: Standardized
	90°	450	2	7.5	0.2	2	Air Bonding: Standardized
8 mil B/1100/CMC Fiber	0°	R. T.	4	165.0	10.6	3	Air Bonding: High Peak
	90°	R. T.	3	7.9	1.5	3	Temp
	0°	450	2	109.0	27.6	1	Air Bonding: High Peak
	90°	450	4	5.3	1.1	4	Temp
	0°	R. T.	4	165.0	10.6	3	Air Bonding: High Peak
	90°	R. T.	3	7.9	1.5	3	Temp
	0°	450	2	109.0	27.6	1	Air Bonding: High Peak
	90°	450	4	5.3	1.1	4	Temp
	0°	R. T.	4	165.0	10.6	3	Air Bonding: High Peak
	90°	R. T.	3	7.9	1.5	3	Temp

TABLE 11 (Cont)

System	Test Orientation	Test °F	U. T. S. Normalized to 50 V/° Fiber		ε T % In./In.	Average Tensile Modulus	Preparation	
			Fiber	o ksi		PSI x 10 ⁶		
5.6 mil B/6061/CMC Fiber	0°	R. T.	4	156.0	16.2	0.51	38.9	Air Bonding
	90°	R. T.	4	6.3	0.3	0.12	14.5	Air Bonding
	0°	450	2	165.0	---	---	---	Air Bonding
	90°	450	1	3.6	---	0.07	14.4	Air Bonding
5.6 mil B/1100/CMC Fiber	0°	R. T.	4	156.0	16.2	0.51	38.9	Air Bonding
	90°	R. T.	4	6.3	0.3	0.12	14.5	Air Bonding
	0°	450	2	~165.0	---	---	---	Air Bonding
	90°	450	1	3.6	---	0.07	14.4	Air Bonding

TABLE 12
450° STRESS RUPTURE RESULTS

<u>Specimen No.</u>	<u>Tape No.</u>	<u>Stress in KSI</u>	<u>% of Static Ult</u>	<u>Duration Hrs.</u>	<u>Remarks</u>
A. CMC Fiber, Longitudinal Direction:					
1237-L1	2992-86	147.3	83	0	Fractured
1237-L2	2922-86	134.1	75	1754.8	Terminated; tensile tested
1237-L3	2922-86	140.1	79	2.9	Fractured
1237-L4	2922-86	144.9	81	0.4	Fractured
1237-L5	2922-86	136.5	77	1254.0	Terminated;
1237-L6	2922-86	138.8	78	0.1	Fractured
B. AVCO Fiber, Longitudinal Direction:					
1238-L1	2922-22	140.6	76	360.6	Terminated
1238-L2	2922-22	133.9	73	1121.5	Terminated; tensile tested
1238-L3	2922-22	146.6	80	145.0	Terminated
1238-L4	2922-22	160.4	87	690.7	Terminated; tensile tested
1238-L5	2922-22	168.0	91	0	Fractured
1238-L6	2922-22	180.5	98	0	Fractured
1238-L7	2922-22	171.7	93	2.0	Fractured
1238-L8	2922-22	165.1	89	719.0	Fractured 184
C. CMC Fiber, Transverse Direction:					
1251-T1	2922-23	5.61	32	40.5	Fractured
1251-T2	2922-23	6.0	34	176.2	Fractured
1256-T3	2922-23	6.26	35	1.2	Fractured
1256-T4	2922-23	5.86	33	350.1	Fractured
1257-T5	2922-23	6.57	37	28.3	Fractured
1257-T6	2922-23	7.07	40	61.3	Fractured
D. AVCO Fiber, Transverse Direction:					
1255-T1	2922-93	6.18	44	72.2	Fractured
1255-T2	2922-93	5.98	43	57.3	Fractured
1250-T3	2922-93	5.77	41	377.3	Fractured
1250-T4	2922-93	6.45	46	66.0	Fractured
1250-T5	2922-93	7.36	52	0	Fractured
1255R-T6	2922-98	6.72	48	16.1	Fractured

TABLE 13
BORON ALUMINUM COMPOSITE BALLISTIC IMPACT TESTS
8 MIL BORSIC 6061 ALUMINUM COMPOSITE, ($\pm 45^\circ/\text{O}_2$)S LAYUP

<u>Specimen No.</u>	<u>Boron Supplier</u>	<u>Specimen Thickness (in.)</u>	<u>Gelatin Weight (g)</u>	<u>Impact Velocity (fps)</u>	<u>Kinetic Energy (ft-lb)</u>	<u>Tip Deflect (in.)</u>	<u>Dent Depth (in.)</u>	<u>Comments</u>
1285A	CMC	0.090	2.55	870	66	---	0.049	Complete fracture at impact site
1285B	CMC	0.090	2.46	860	62	0.348	0.072	Cracks at impact site
1286A	AVCO	0.094	2.55	855	64	0.764	0.045	Cracks at impact site
1286B	AVCO	0.094	2.58	870	67	0.385	0.061	Cracks at impact site

TABLE 14
CHARACTERIZATION: MATERIAL TRACEABILITY

Panel #	Test	Fiber Orientation	Tape #	Fiber Spool #	Average	
					Fiber Diameter Mils	Fiber U. T. S. KSI
1258, 1259, 1267A	Tensile	Unidirectional	2922-93	14A-1008 12X-7304	8.0 8.0	573 571
1267B, 1268A, 1268B	Tensile	Unidirectional	2922-95	19-4971 19-4973	8.0 7.9	564 563
1260	Tensile	Unidirectional	2922-94	12-7304 19-4973	8.0 7.9	571 563
1265A, 1265B, 1266A, 1266B	Tensile	Blade	2922-94	19-4973		
1269A, 1269B	In Plane Shear	Unidirectional	2922-95	19-4971 19-4973	8.0 7.9	564 563
1270A, 1276A, 1276B	In Plane Shear	Blade	2922-95	19-4973		
1275A, 1275B	In Plane Shear	Blade	2922-94	12-7304 19-4973	8.0 7.9	571 563
1270B	In Plane Shear	Blade	2922-96	19-4971 19-4972	8.0 8.0	564 580
1271A, 1271B, 1272	Tension-Tension Fatigue	Blade	2922-96	19-4972		
1273R, 1274R	Tension-Tension Fatigue	Blade	2922-98	12-7305 11-2708	8.0 7.9	497 535
1277A, 1277B	Creep-Stress Rupture	Blade	2922-96	19-4971 19-4972	8.0 8.0	564 580
1278A, 1278B	Creep-Stress Rupture	Blade	2922-97	19-4972		
1277C	Creep-Stress Rupture	Blade	2922-97	19-4972 12-7305	8.0 8.0	580 497
1279A, 1279B	Stress Corrosion	Blade	2922-97	19-4972 12-7305	8.0 8.0	580 497

TABLE 15
CHARACTERIZATION: PANEL STRENGTH PROPERTIES FOR THE 8 MIL
BORON/60s1⁽¹⁾/CMC FIBER SYSTEM

1. Static Tensile Properties

# Specimen	Orient.	V/°	U. T. S. KSI	Normalized To 50V/° Fiber U. T. S. KSI	Modulus psi X 10 ⁶	% in/in
<u>R. T. Tensile</u>						
1258-L1	0	51.8	203.1	195.9	32.20	0.72
1258-L2	0	51.8	202.1	194.9	33.70	0.71
1267A-1	0	51.8	187.2	180.5	30.00	0.69
1267A-2	0	50.8	180.3	177.2	30.71	0.64
	\bar{X}			187.1	31.65	0.69
	σ			9.7	1.64	0.04
1259-T1	90	51.8	26.8	25.9	19.90	0.50
1259-T2	90	51.8	28.7	27.7	20.60	0.62
1268B-T1	90	50.2	25.5	25.4	20.70	0.47
1268B-T2	90	50.2	22.3	25.4	20.70	0.26
	\bar{X}			26.1	20.48	0.46
	σ			1.1	0.39	0.15
<u>450° F Tensile</u>						
1258-L7	0	51.8	202.1	195.0	33.40	-
1258-L8	0	53.0	211.2	199.1	33.60	-
1267A-L3	0	50.8	174.1	170.2	Strain Gage Failure	
1267A-L4	0	50.8	179.0	176.2	Strain Gage Failure	
	\bar{X}			185.1	33.5	-
	σ			14.1	-	-
1259-T7	90	51.8	17.7	17.1	24.71	0.66
1259-T8	90	51.8	17.2	16.6	20.33	0.34
1268B-T3	90	48.4	16.8	17.4	19.84	0.50
1268B-T4	90	49.3	16.8	17.0	19.84	0.34
	\bar{X}			17.0	21.18	0.46
	σ			0.3	2.36	0.15

2. Static Tensile Properties After 1000 Thermal Cycles: -65°F to 450°F

<u>R. T. Tensile</u>						
1258-L3	0	50.8	192.2	189.1	32.30	0.69
1258-L4	0	51.8	192.1	185.3	31.20	0.67
1267A-L5	0	51.8	168*	162.2*	29.31	0.64
1267A-L6	0	51.8	188.0	181.5	29.90	0.70
	\bar{X}			179.5	30.68	0.68
	σ			12.0	1.34	0.03
1259-T3	90	-	Warped	-		
1259-T4	90	-	Warped	-		
1268B-T5	90	-	Warped	-		
1268B-T6	90	49.3	27.0	27.4	17.31	0.24

(1) Unidirectional 6 ply panel

* Slight warp and twist

TABLE 15 (Continued)

2. Static Tensile Properties After 1000 Thermal Cycles; -65°F to 450°F (Continued)

# Specimen	Orient.	V/°	U. T. S. KSI	Normalized To 50V/° Fiber U. T. S. KSI	Modulus psi X 10 ⁶	% in/in
<u>450°F Tensile</u>						
1258-L5	0	51.8	215.2	207.5	30.60	0.84
1258-L6	0	50.8	202.3	198.8	30.60	0.81
1267A-L7	0	52.7	188.1	178.4	30.60	0.78
1267A-L8	0	51.8	165.0*	159.3*	31.33	0.64
	\bar{X}			186.0	30.78	0.77
	σ			21.6	0.36	0.09
1259-T5	90	-	Warped			
1259-T6	90	-				
1268B-T7	90	-				
1268B-T8	90	-				

3. Static Tensile Properties After 168 Hour Salt Fog Test

R. T. Tensile

1267B-L1	0	50.2	>181.1	>180.3	32.70	>0.65
1267B-L2	0	49.3	186.0	188.6	30.61	0.69
1267C-L1	0	51.1	203.0	198.6	30.60	0.76
1267C-L2	0	50.2	200.9	200.2	30.90	0.75
	\bar{X}			191.9	31.2	0.71
	σ			> 9.3	1.0	-
1260-T1	90	49.3	27.5	27.9	19.00	0.61
1260-T2	90	49.3	30.0	30.4	21.00	0.91
1268A-T1	90	50.2	23.9	23.8	19.80	0.48
1268A-T2	90	51.1	28.1	27.5	19.81	0.73
	\bar{X}			27.4	19.90	0.68
	σ			2.7	0.82	0.18

450°F Tensile

1267B-L3	0	50.2	194.0	193.2	34.80	>0.52
1267B-L4	0	50.2	192.1	191.2	34.20	0.38
1267C-L3	0	49.3	191.0	193.7	36.11	0.73
1267C-L4	0	50.2	174.0		31.50	-
	\bar{X}			192.7	34.15	
	σ			1.3	1.94	
1260-T3	90	49.3	15.6	15.8	17.20	0.24
1260-T4	90	49.3	17.8	18.0	17.30	0.42
1268A-T3	90	50.2	18.3	18.2	15.40	0.39
1268A-T4	90	50.2	17.7	17.6	15.40	0.51
	\bar{X}			17.4	16.32	0.39
	σ			1.1	1.07	0.11

* Slight warp and twist

TABLE 16
CHARACTERIZATION: PANEL STRENGTH PROPERTIES FOR THE 8 MIL
BORON/6061/CMC FIBER SYSTEM

Static Tensile Properties for Blade Shell⁽¹⁾

# Specimen	Orient.	V/°	U. T. S. KSI	Modulus psi X 10 ⁶	% in/in
<u>R. T. Tensile</u>					
1265A-1	Axial	31.2	80.4	16.0	-
1265A-2	Axial	31.2	86.1	-	-
1265A-3	Axial	31.2	88.9	-	-
1265A-4	Axial	31.2	86.7	-	-
	\bar{X}		85.5		
	σ		3.6		
<u>450° F Tensile</u>					
1265B-L1	Axial	31.2	73.9	13.5	-
1265B-L2	Axial	30.7	72.7	12.9	-
1265B-L3	Axial	31.2	75.4	13.2	-
1265B-L4	Axial	31.2	77.3	13.1	-
	\bar{X}		74.8	13.2	
	σ		2.0	0.2	
Static Tensile Properties After 1000 Thermal Cycles: -65° F to 450° F					
<u>R. T. Tensile</u>					
1266A-1	Axial	31.2	77.1	14.10	0.90
1266A-2	Axial	31.2	77.3	15.00	0.85
1266A-3	Axial	31.2	81.9	14.81	1.00
1266A-4	Axial	31.2	80.3	14.80	0.98
	\bar{X}		79.2	14.68	0.93
	σ		2.3	0.40	-
<u>450° F Tensile</u>					
1266B-1	Axial	31.2	64.2	13.80	0.68
1266B-2	Axial	31.2	65.6	14.10	0.50
1266B-3	Axial	31.2	62.4	11.71	0.79
1266B-4	Axial	31.2	61.6	11.60	1.16
	\bar{X}		63.4	12.80	0.78
	σ		1.8	1.33	-

(1) Blade specimen layup is T2 /+ 45° -45° -45° +45°/T2.

TABLE 17
CHARACTERIZATION 450°F STRESS RUPTURE RESULTS (1)

<u>Specimen #</u>	<u>Tape #</u>	<u>Stress in KSI</u>	<u>% of U. T. S. *</u>	<u>Duration Hours</u>	<u>Remarks</u>
1277A-L1	2922-97	68.9	95	-	Fractured
1277B-L2	2922-97	61.5	85	-	Fractured
1277B-L3	2922-97	51.6	71	3100	Terminated
1277C-L4	2922-97	55.5	76	-	Fractured
1277A-L5	2922-97	53.7	74	2600	Still running

* This is based on lowest static tensile strength at 450°F of 72.7 KSI.

(1) Blade specimen orientation, see table 16.

TABLE 18
CHARACTERIZATION 450°F CREEP TEST RESULTS (1)

<u>Specimen #</u>	<u>Tape #</u>	<u>Stress in KSI</u>	<u>% of U. T. S.</u>	<u>Remarks</u>
1277C-L1	2922-97	55.98	77	Slipped in grips first minute after loading.
12776-L2	2922-97	45.40	62	Tested 260 hours.
12776-L3	2922-97	48.75	67	Slipped in grips first minute after loading.
1278A-L4	2922-97	42.20	58	Tested 260 hours.
1278A-L5	2922-97	30.60	42	Tested 50 hours.
1278B-L6	2922-97	19.6	27	Tested 35 hours.
1278B-L7	2922-97	10.6	15	Tested 120 hours.
1278B-L8	2922-97	5.3	7	Tested 35 hours.

Use U. T. S. of 72.7 KSI, lowest tensile strength at 450°F.

(1) Blade specimen orientation, see table 16.

TABLE 19
ROOM TEMPERATURE STRESS CORROSION/RESULTS (1)

Specimen #	Tape #	Coarse	Stress KSI	% of U. T. S.	Duration Hours	Fracture
1279A-L1	2922-97	CMC	72.4	90	0	Fractured on loading
1279A-L2	2922-97	CMC	62.9	78	108.2	Fractured
1279A-L3	2922-97	CMC	65.2	81	~33	Timer malfunctioned, fractured.
1278A-L4	2922-97	CMC	65.5	81	4	Fractured.
1278A-L5	2922-97	CMC	63.9	80	6.7	Fractured.
1278B-L6	2922-97	CMC	63.3	79	144.6	Fractured.

Use U. T. S. of 80.4 KSI lowest tensile strength at R. T.

(1) Blade specimen orientation, see table 16.

TABLE 20
RAIL SHEAR SPECIMEN TEST RESULTS

Configuration	Temp °F	Specimen S/N	Maximum Attained Shear Stress-KSI	Shear Modulus 10 ⁶ psi	Apparent B/Al Composite Shear Stress-KSI	Apparent Titanium Shear Stress-KSI	B/Al Composite Shear Modulus 10 ⁶ psi	Titanium ⁽¹⁾ Shear Modulus 10 ⁶ psi
2 layers T1 4 layers 0° B/Al	70	1269A-1	35.5	5.06	29.7	44.2	4.23	6.3
2 layers T1 4 layers 0° B/Al	70	1270B-B2	36.1	5.40	32.1	42.1	4.8	6.3
2 layers T1 4 layers ± 45° B/Al	70	1269B-1	33.3	5.57	30.3	37.6	5.08	6.3
2 layers T1 4 layers ± 45° B/Al	70	1270A-B1	33.3	7.06	35.6	29.7	7.57	6.3
2 layers T1 4 layers ± 45° B/Al	450	1275A-B1	33.3	6.19	35.2	30.5	6.55	5.6
2 layers T1 4 layers ± 45° B/Al	450	1275B-B2	24.0	7.82	28.4	17.4	9.27	5.6
2 layers T1 4 layers ± 45° B/Al (1000 thermal cycles	70	1276B-B2	28.0	7.90	31.8	22.3	8.97	6.3
2 layers T1 4 layers ± 45° B/Al (1000 thermal cycles	70	1276A-B1	38.9	7.50	43.0	32.7	8.3	6.3

(1) From the literature

AIR BONDING HARDWARE

- 1. PICTURE FRAME & MUSH 2. FLOATING PRESSURE PLATE
3. PANEL 4. SEPARATOR COVER**

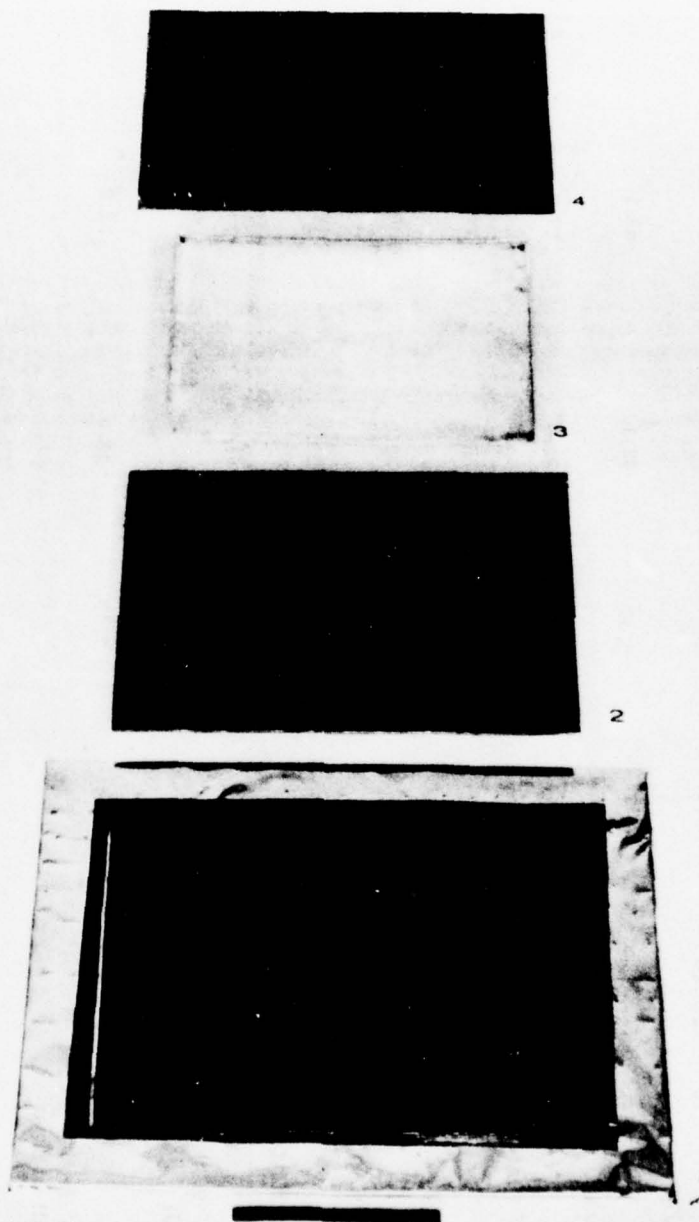


FIGURE 1. PICTURE FRAME AND PRESSURE PLATE FOR BONDING

U.S.A.F. PROGRAM:
AIR BONDED, F.O.D. RESISTANT
METAL MATRIX FAN BLADES

I. SCREENING

A. GENERAL EVALUATION

1. 8 MIL B & 5.6 MIL B
2. 1100 & 6061 METAL MATRIX
3. CMC FIBER & AVCO FIBER

B. ADVANCED EVALUATION

1. 2 MOST PROMISING SYSTEMS AND PROCESSING FROM ABOVE
2. FATIGUE, THERMAL CYCLE, RUPTURE, IMPACT TESTS TO
DELINEATE BEST SYSTEM.

II. CHARACTERIZATION

A. BEST SYSTEM AND PROCESSING FROM 1 ABOVE

B. CHARACTERIZE UNIAXIAL & BLADE ORIENTATIONS

FIGURE 2. PROGRAM: MAJOR PHASES

GENERAL SCREENING EVALUATION

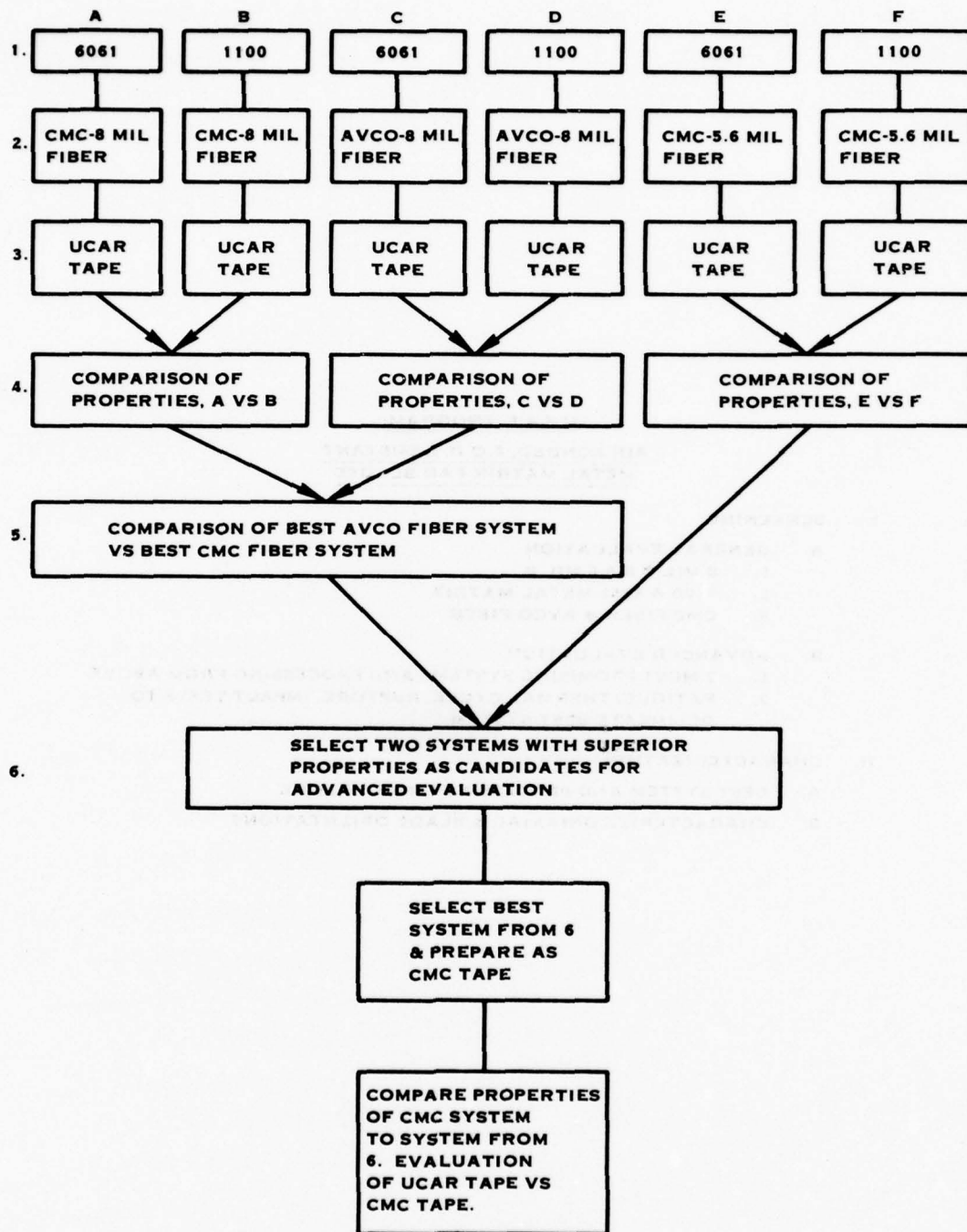


FIGURE 3. SCREENING PHASE

1100/8 MIL B/1100/ CMC FIBER

LOT # (SPOOL)	14A-890	14A-880	14A-879	14A-879	14A-864	14A-864	13-3074	13-3071
DIA. MILS	8.05	8.00	8.10	8.0	7.9	7.90	8.00	8.00
UTS, KSI	519	476	597	597	594	594	533	545
WIND WIDTH	7.31	6.58	1.24	3.6	11.46	1.35	7.25	6.57
	2922-12			2922-13			2922-14	

FIBER-UTRC TESTS
20' BEGINNING & END
OF EACH SPOOL

VISUAL
UTS

<u>TAPE (UCAR)</u>			
TAPE #	2922-12	2922-13	2922-14
FIL/IN.	92.7	92.7	92.7
VOL % FIBER	52.3	51.9	51.6
GR/IN ²	0.371	0.368	0.374
THICK. IN.	0.012-0.013	0.013-0.0135	0.013-0.0135

TAPE - UTRC TESTS
20 FIBERS-EXTRACTION
TAPE EDGE
BEND TESTS - 3
SEGMENTS/TAPE

TAPE # 2922-12

MICROGRAPH
X-RAY
DENSITY
FIBER EXT: 0°

PANEL BSAD #1209
6.2" X 5.5" UNIAXIAL: 0°
1010°F ± 10°F, 5500 ± 500 PSI
10 MIN

TENSILE
R.T.: 0°-2, 90°-4

IMPACT
R.T.: 0°-5
FIBER EXT: 0°-1

MICROGRAPH
X-RAY
DENSITY
FIBER EXT: 0°

PANEL BSAD #1210
UNIAXIAL: 90°
1010°F ± 10°F, 5500 ± 500 PSI
10 MIN

TENSILE
450°F: 90°-4

IMPACT
R.T.: 90°-5
FIBER EXT: 0°-1

MICROGRAPH
X-RAY
DENSITY
FIBER EXT: 0°

PANEL BSAD #1211
6.2" X 5.5" UNIAXIAL: 0°
1010°F ± 10°F, 5500 ± 500 PSI
10 MIN

TENSILE
R.T.: 0°-2
4500: 0°-4
TORSION, R.T.: 0°-2

SCREENING - GENERAL

FIGURE 4. TYPICAL GENERAL SCREENING EVALUATION FOR ONE COMPOSITE SYSTEM

ADVANCED EVALUATION

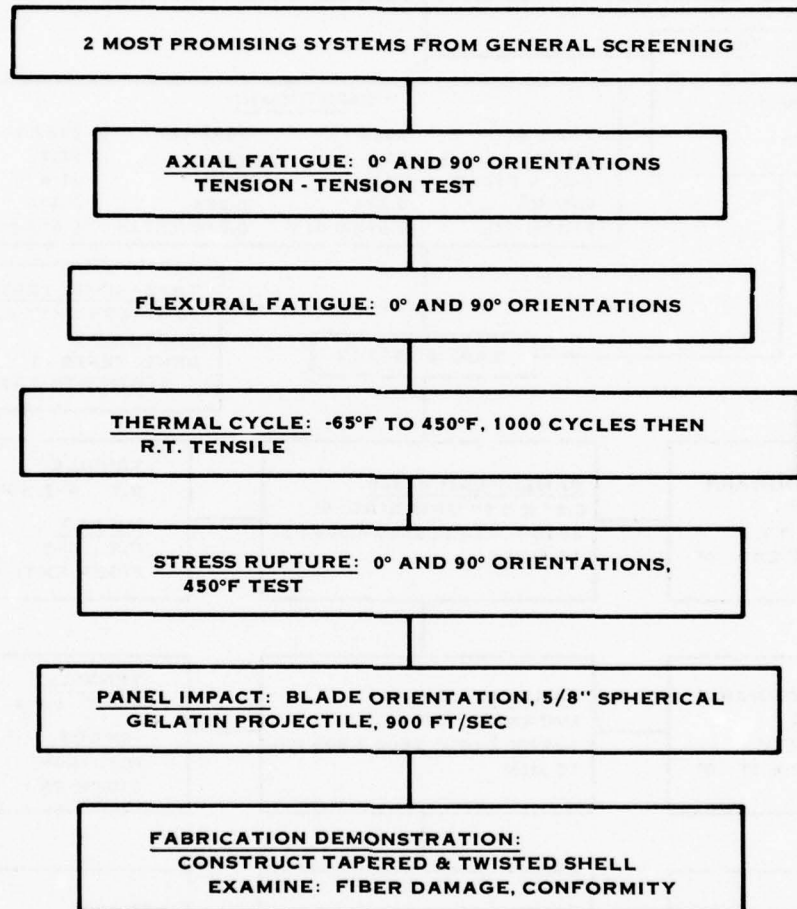
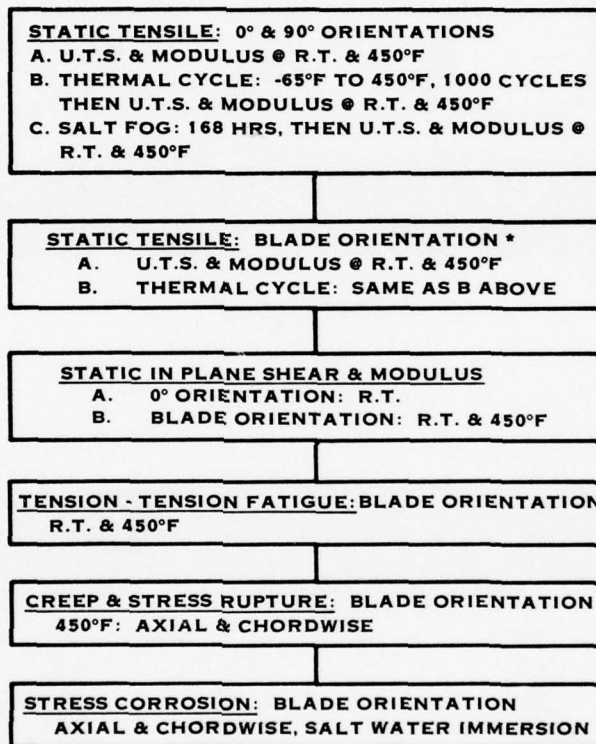


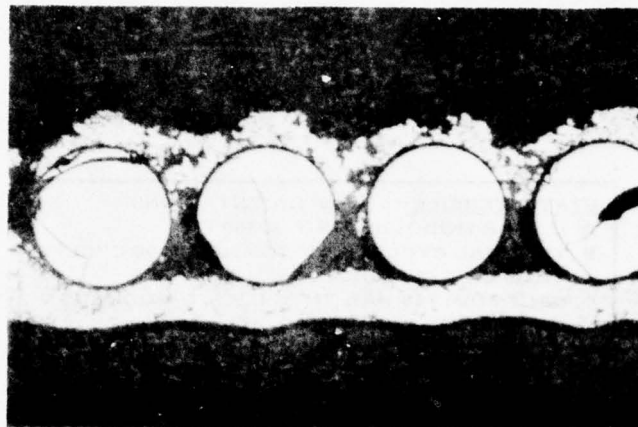
FIGURE 5. ADVANCED EVALUATION

CHARACTERIZATION: BEST SCREENING SYSTEM

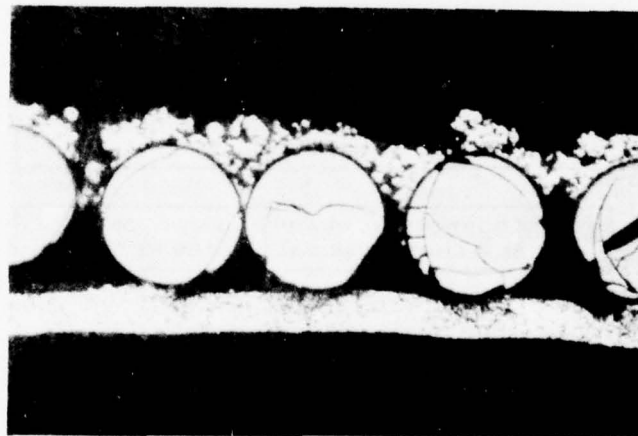


*NOTE: PLUS TITANIUM FACE SHEET

FIGURE 6. CHARACTERIZATION STUDY

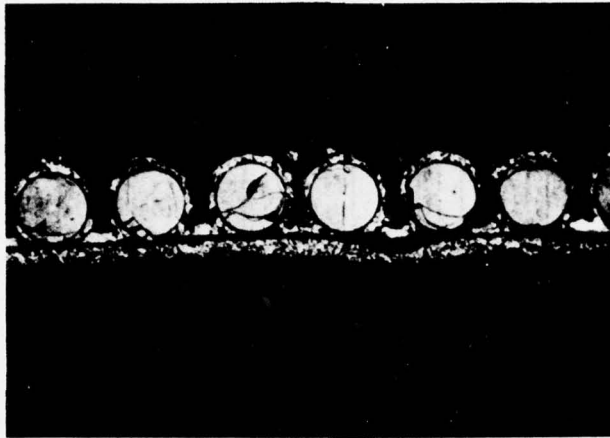


TAPE 8.0 - 6061-2M-2
100X

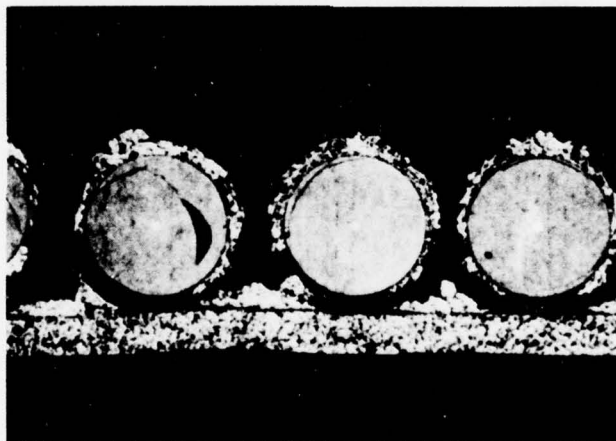


TAPE 8.0 - 6061 - 2M-3
100X

FIGURE 7. CMC TAPES 8.0 - 6061 - 2M-2 AND 8.0 - 6061 - 2M-3
8 MIL BORON/6061/CMC FIBER SYSTEM



TAPE 2873-55
50X



TAPE 2873-55
100X

FIGURE 8. UCAR TAPE 2873-55, 8 MIL BORON/6061/CMC FIBER SYSTEM

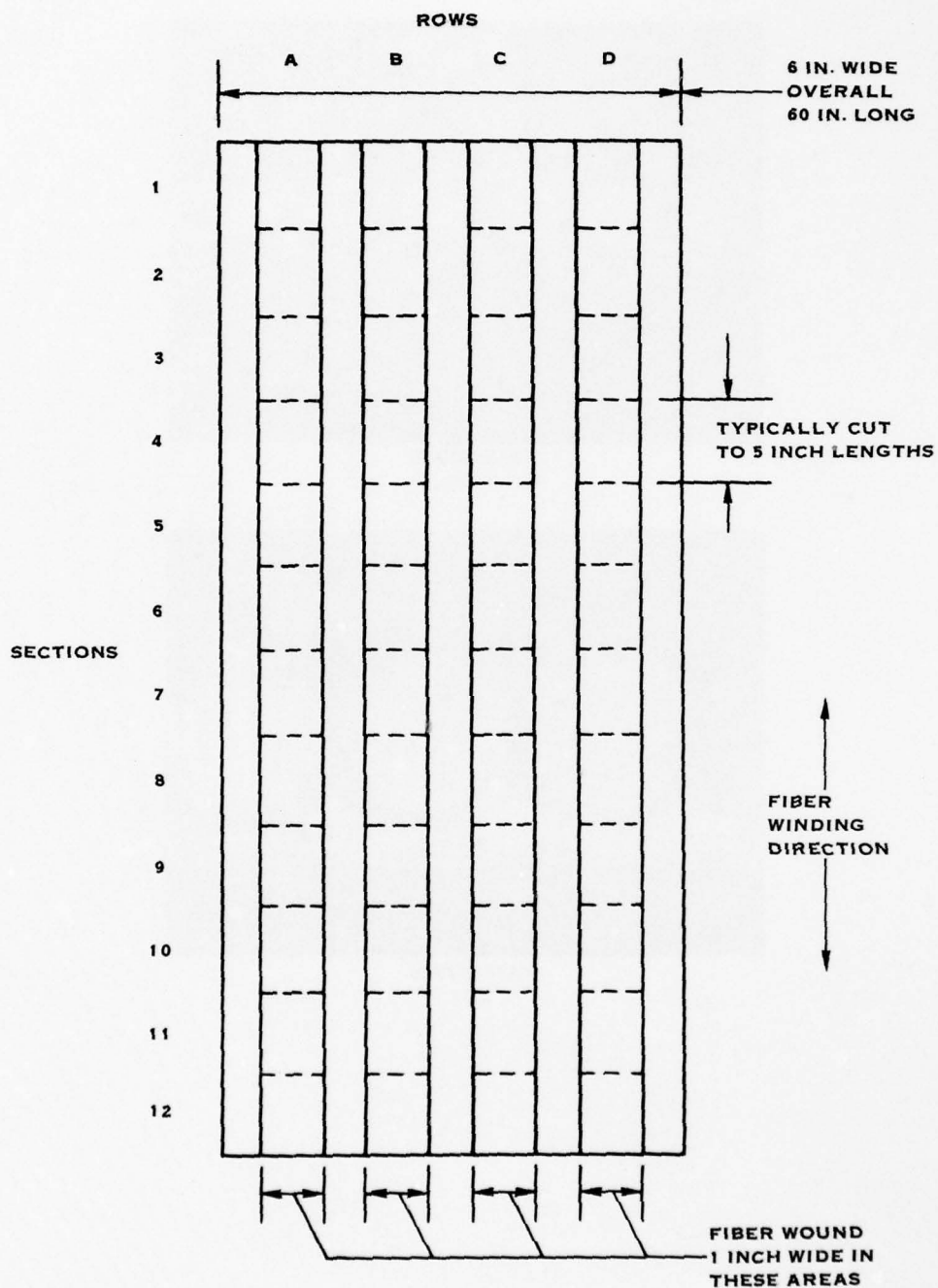
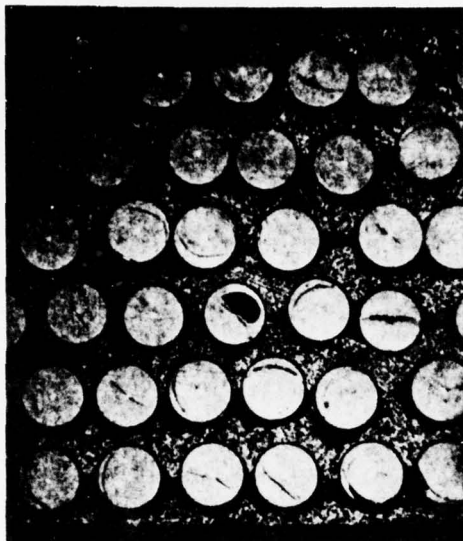
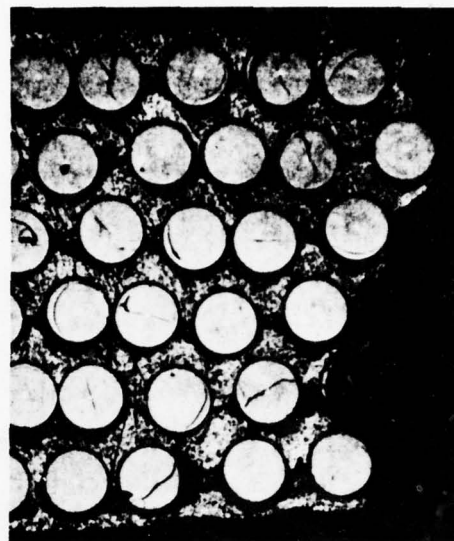


FIGURE 9. PLASMA SPRAYED TAPE CONFIGURATION



TYPICAL CROSS SECTION
50X

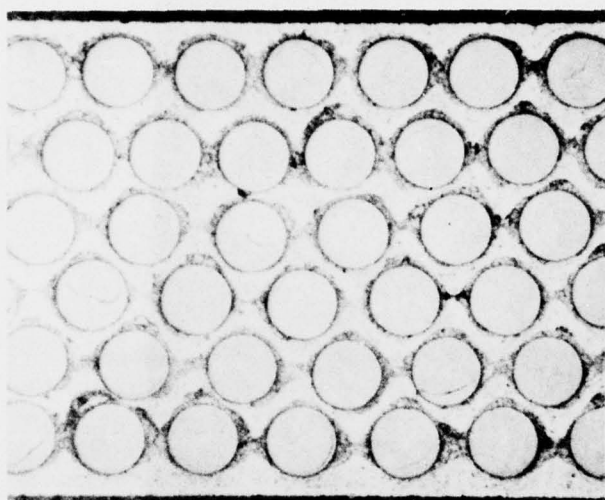


FRACTURE EDGE
50X

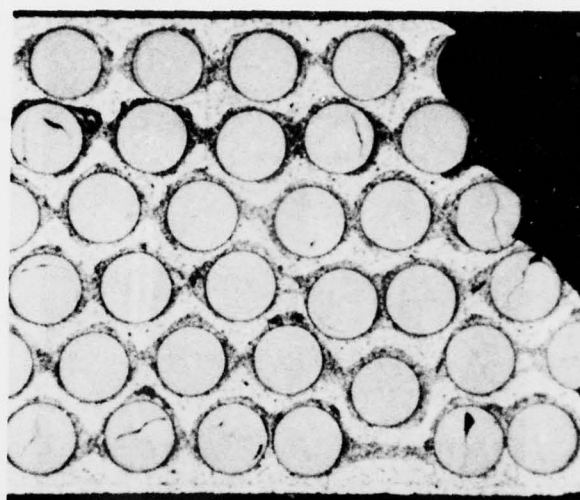


TOUCHING INTERIOR FIBERS
500X

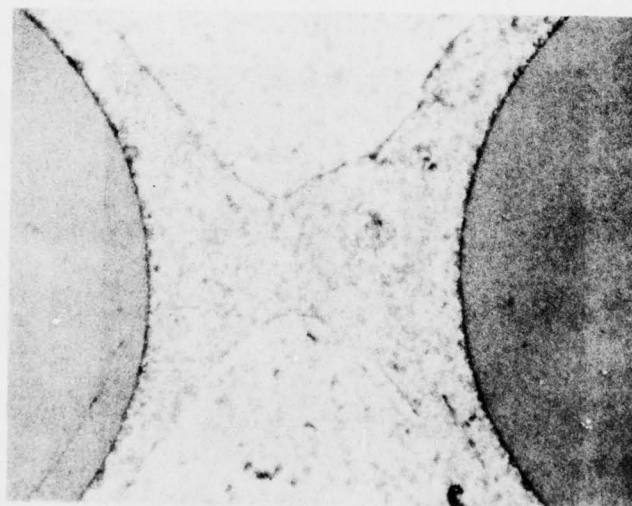
FIGURE 10. BSAD 1148, TAPE CMC 8, 0-6061-2M-3, 8 MIL BORON/
6061/CMC FIBER SYSTEM



TYPICAL CROSS SECTION
50X

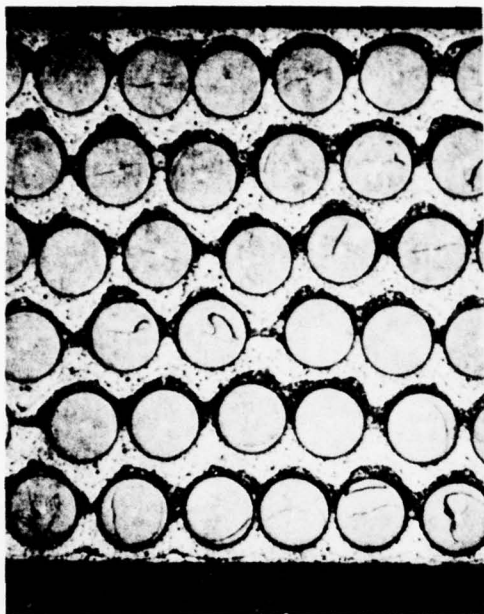


FRACTURE EDGE
50X

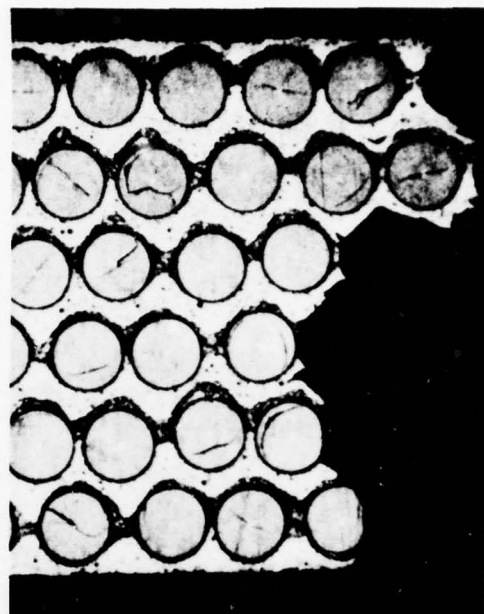


EDGES OF TWO INTERIOR FIBERS
500X

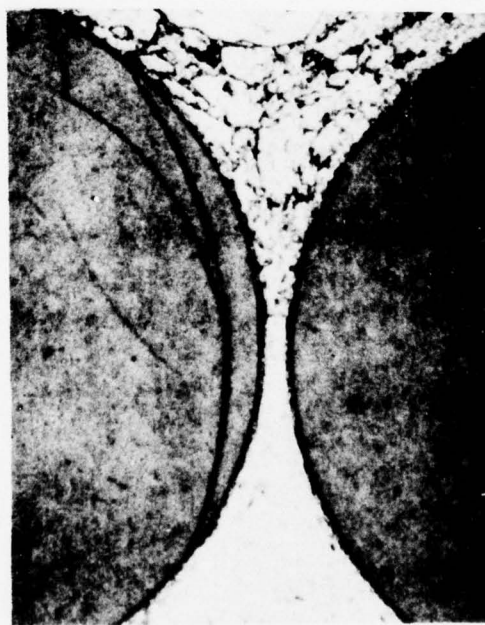
**FIGURE 11. BSAD 1169, TAPE UCAR 2873-55, 8 MIL BORON/6061/
CMC FIBER SYSTEM—UCAR TAPE, 94 ± 2 ENDS/INCH**



TYPICAL CROSS SECTION
50X

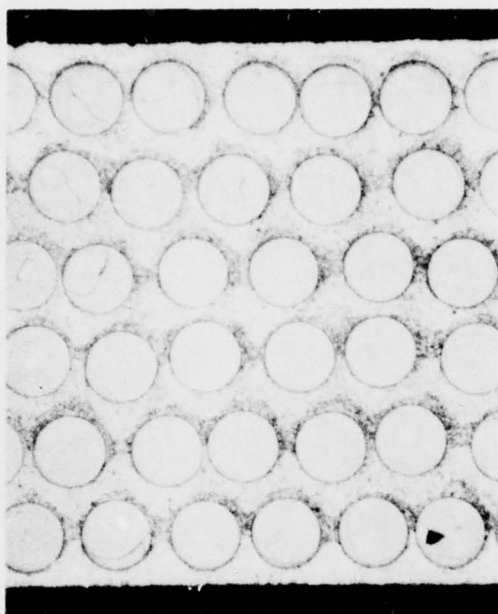


FRACTURE EDGE
50X

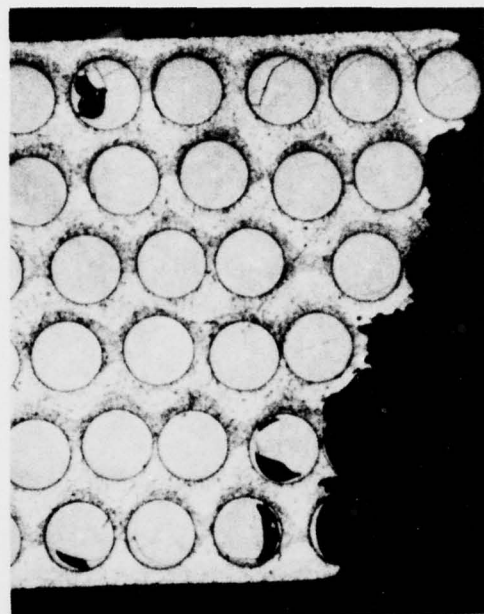


EDGES OF TWO INTERIOR FIBERS
500X

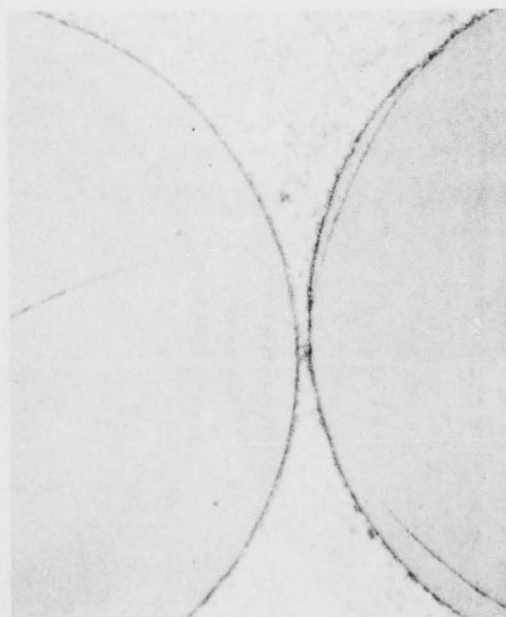
FIGURE 12. BSAD 1164, TAPE CMC 8. 0-6061-2M-3, 8 MIL BORON/6061/
CMC FIBER SYSTEM



TYPICAL CROSS SECTION
50X

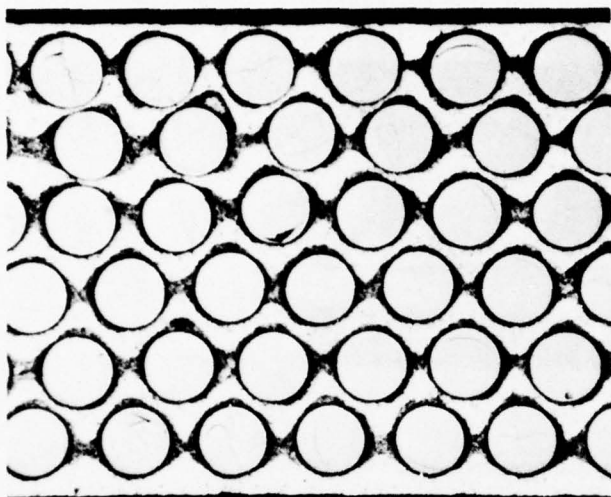


FRACTURE EDGE
50X

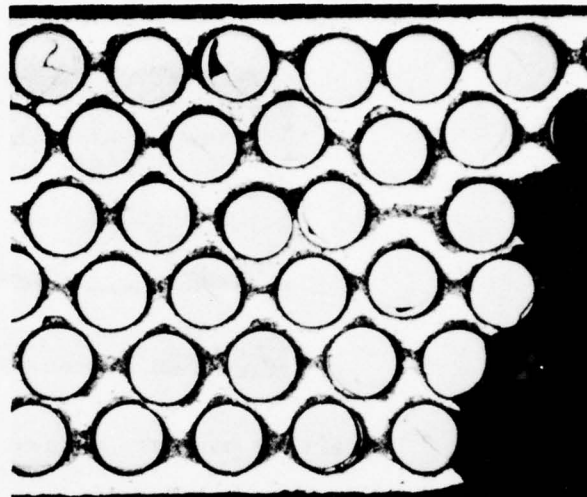


EDGE OF TWO INTERIOR FIBERS
500X

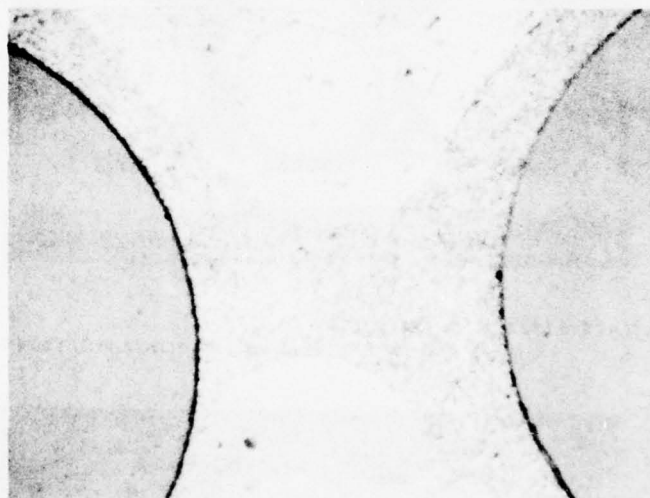
FIGURE 13. BSAD 1154, TAPE CMC 8. 0-6061-2M-3, 8 MIL BORON/6061/
CMC FIBER SYSTEM



TYPICAL CROSS SECTION
50X



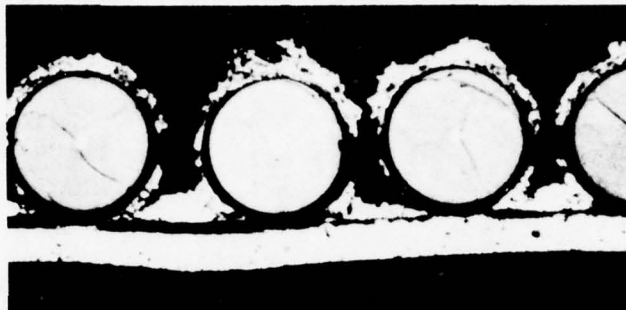
FRACTURE EDGE
50X



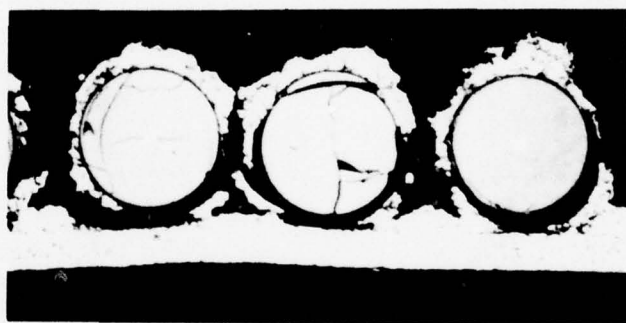
EDGES OF TWO INTERIOR FIBERS
500X

FIGURE 14. BSAD 1168, TAPE UCAR 2873-55, 8 MIL BORON/6061/
CMC FIBER SYSTEM

A. TAPE #2922-21: AVCO FIBER
6061 SPRAY/8 MIL BORON/2 MIL 6061 FOIL



B. TAPE #2922-27: AVCO FIBER
1100 SPRAY/8 MIL BORON/2 MIL 1100 FOIL

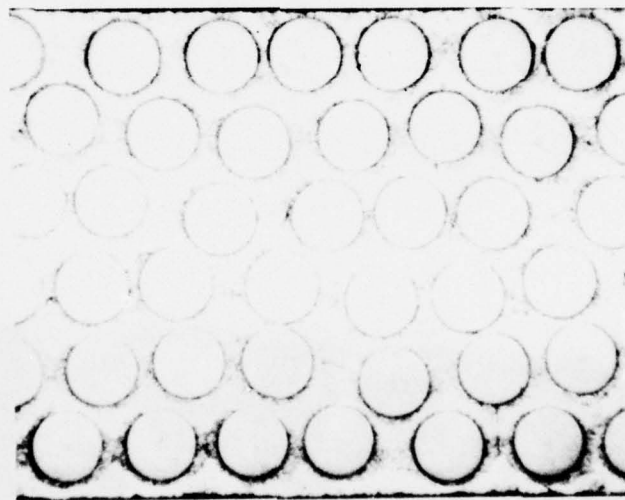


C. TAPE #2922-12: CMC FIBER
1100 SPRAY/8 MIL BORON/2 MIL 1100 FOIL



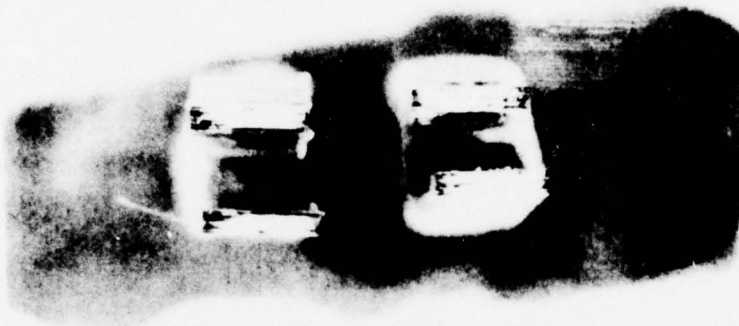
S 48940

FIGURE 15. UCAR TAPE 2922-21, UCAR TAPE 2922-27, UCAR TAPE 2922-12

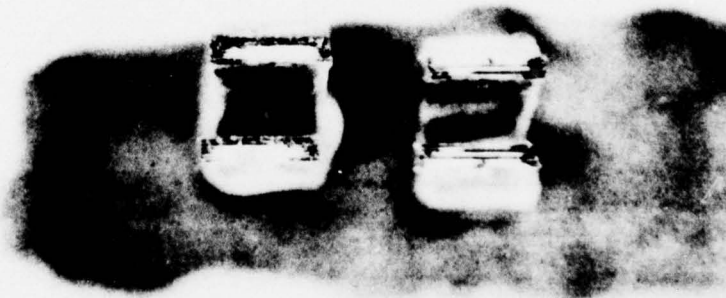


50X

**FIGURE 16. STRUCTURE OF BSAD 1215, TAPE UCAR 2922-21, 8 MIL BORON/
6061/AVCO FIBER SYSTEM**



TENSILE RT 90°



TENSILE RT 90°

FIGURE 17. 6061/8 MIL B/6061 AVCO FIBER TENSILE SPECIMEN



IMPACT RT 0°



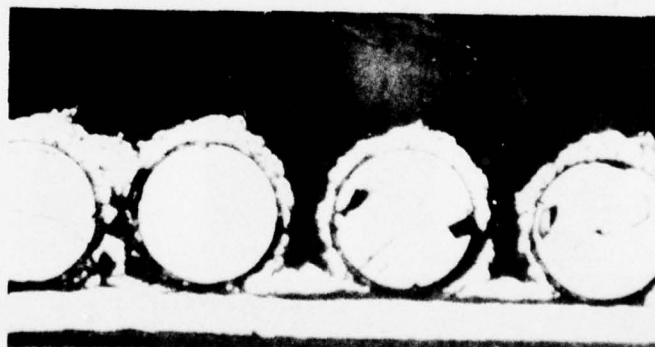
IMPACT RT 90°

FIGURE 18. 6061/8 MIL B/6061 AVCO FIBER IMPACT SPECIMEN



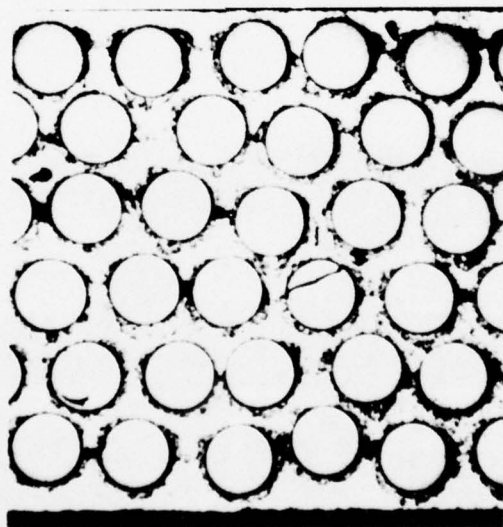
100X

FIGURE 19. UCAR TAPE 2922-27, 8 MIL BORON/6061/AVCO FIBER SYSTEM



100X

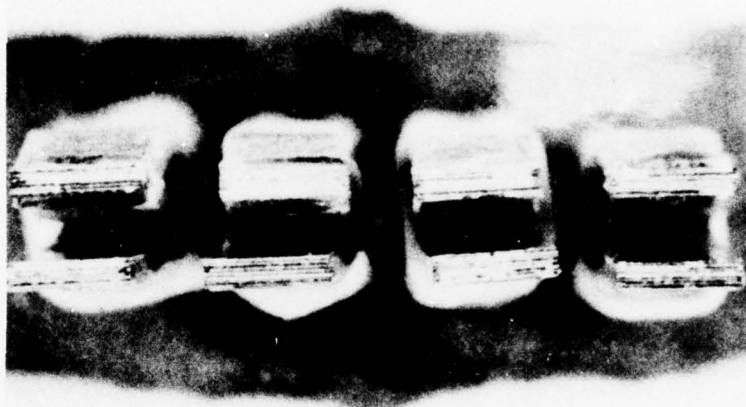
FIGURE 20. TYPICAL STRUCTURE OF UCAR TAPE 2922-28, 8 MIL BORON/1100/AVCO FIBER SYSTEM



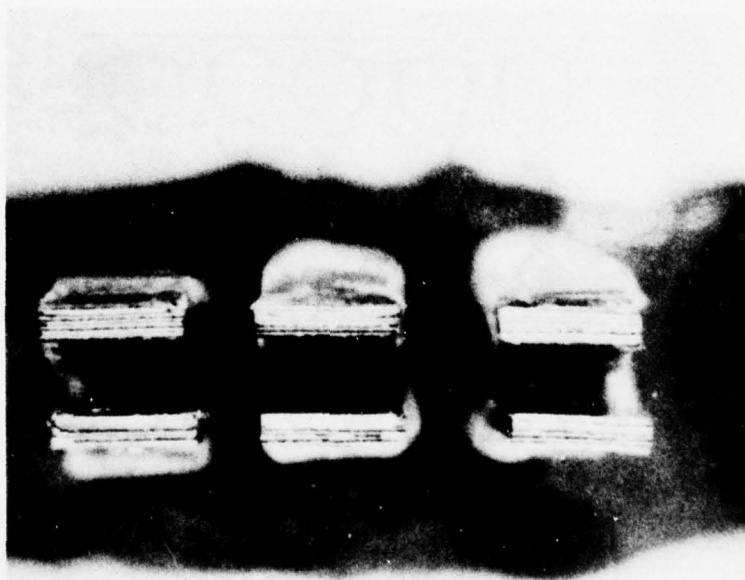
50X

FIGURE 21. BSAD 1212, 8 MIL BORON/1100/AVCO FIBER SYSTEM

1100/8 MIL B/1100 AVCO FIBER



TENSILE RT 90°



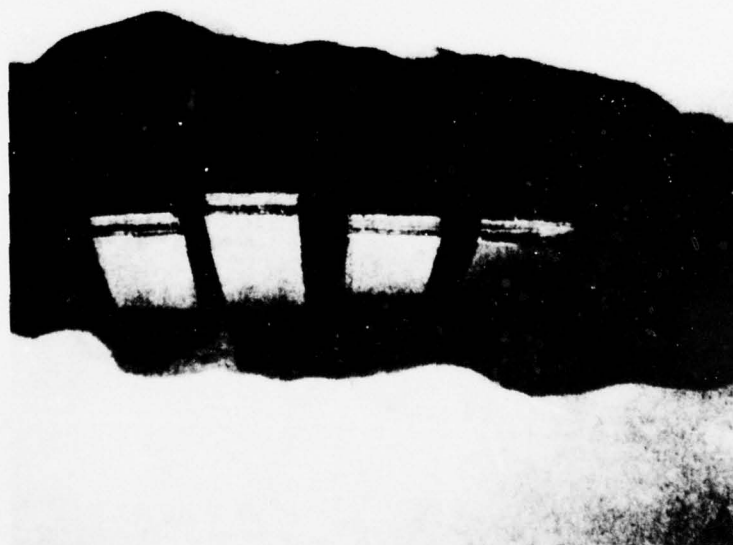
TENSILE RT 90°

FIGURE 22. 1100/8 MIL B/1100 AVCO FIBER TENSILE SPECIMEN

1100/8 MIL B/1100 AVCO FIBER



IMPACT RT 0°



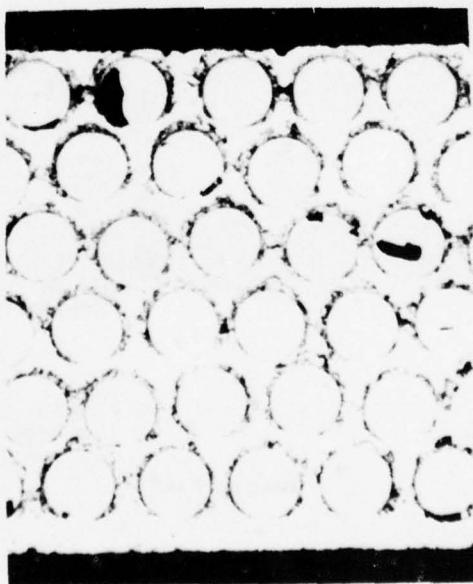
IMPACT RT 90°

FIGURE 23. 1100/8 MIL B/1100 AVCO FIBER IMPACT SPECIMEN



100X

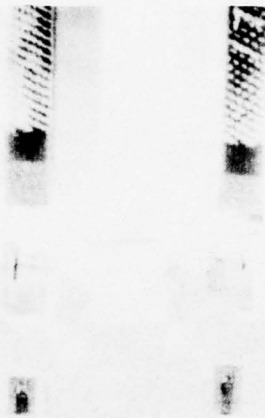
FIGURE 24. UCAR TAPE, 2922-12, 8 MIL BORON/1100/ CMC FIBER SYSTEM



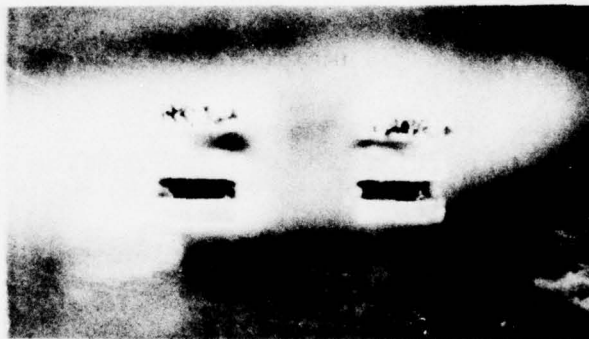
50X

FIGURE 25. BSAD 1209, TAPE UCAR 2922-12, 8 MIL BORON/1100/ CMC FIBER SYSTEM

1100/8 MIL B/1100 CMC FIBER



TENSILE RT 0°



TENSILE RT 0°



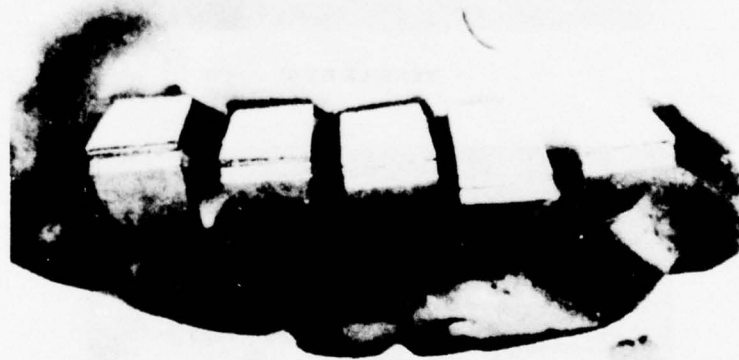
TENSILE RT 90°

FIGURE 26. 1100/8 MIL B/1100 CMC FIBER TENSILE SPECIMEN

1100/8 MIL B/1100 CMC FIBER



IMPACT RT 0°



IMPACT RT 90°

FIGURE 27. 1100/8 MIL B/1100 CMC FIBER IMPACT SPECIMEN

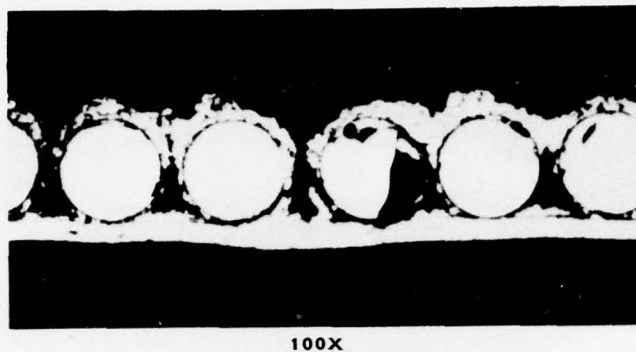


FIGURE 28. UCAR TAPE 2922-20, TAPE UCAR 2922-20, 5.6 MIL BORON/
6061/CMC FIBER SYSTEM

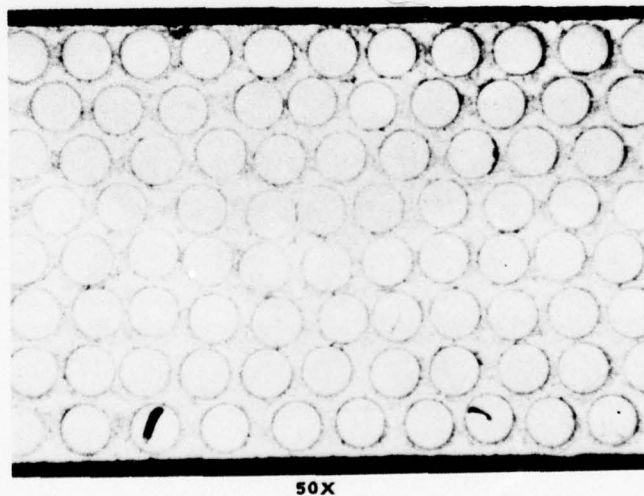
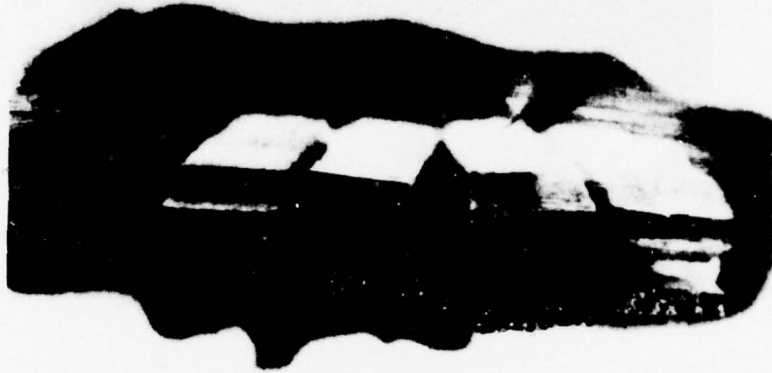


FIGURE 29. BSAD 1221, TAPE UCAR 2922-20, 5.6 MIL BORON/6061/
CMC FIBER SYSTEM

6061/5.6 MIL B/6061 CMC FIBER

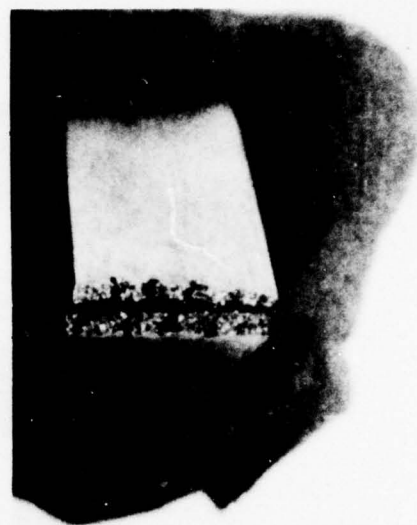
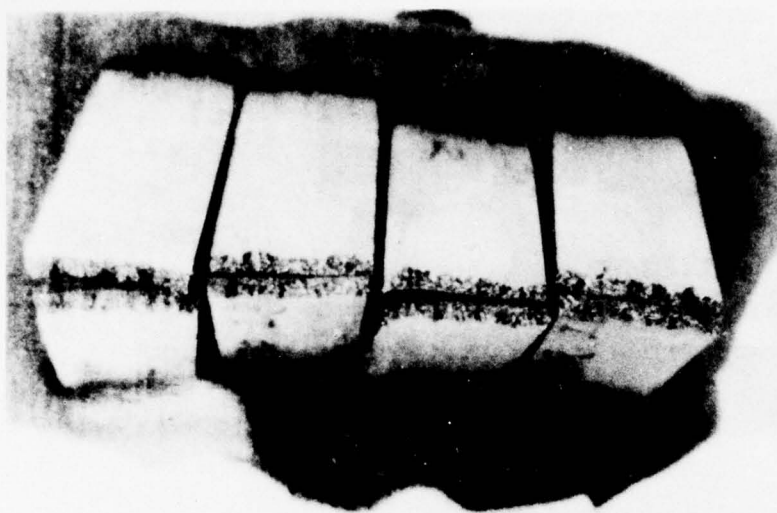


TENSILE RT 0°

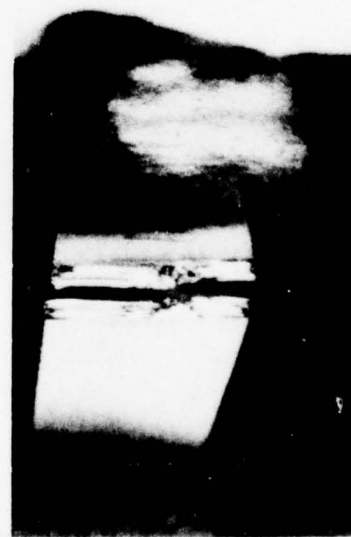


TENSILE RT 90°

FIGURE 30. 6061/5.6 MIL B/6061 CMC FIBER TENSILE SPECIMEN

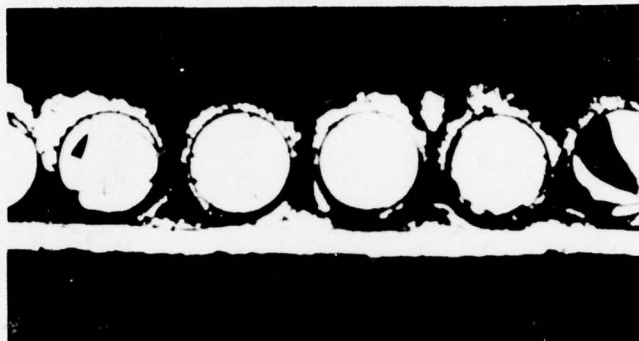


IMPACT RT 0°



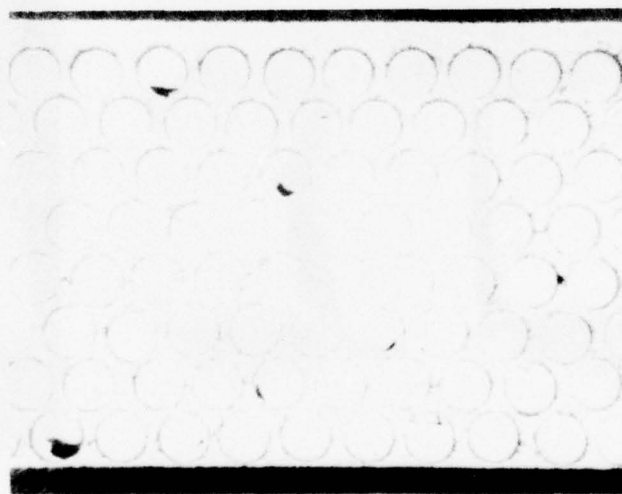
IMPACT RT 90°

FIGURE 31. 6061/5.6 MIL B/6061 CMC FIBER IMPACT SPECIMEN



100X

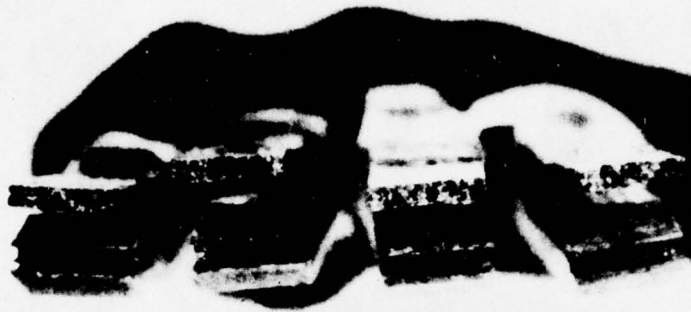
FIGURE 32. UCAR TAPE 2922-16, 5.6 MIL BORON/1100/CMC FIBER SYSTEM



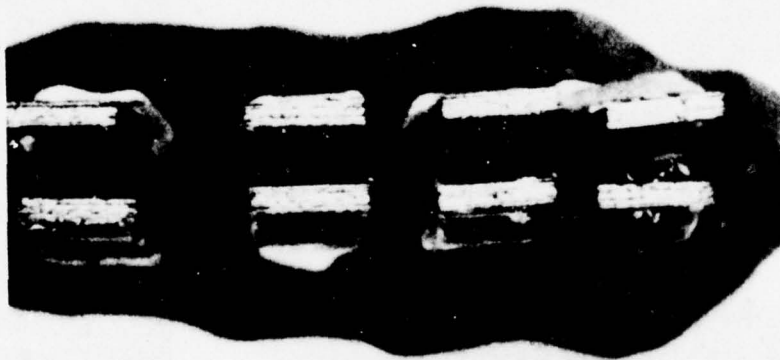
50X

FIGURE 33. BSAD 1226, TAPE UCAR 2922-16, 5.6 MIL BORON/1100/CMC FIBER SYSTEM

1100/5.6 MIL B/1100 CMC FIBER



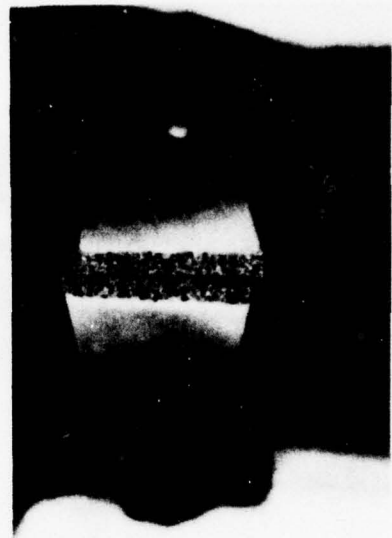
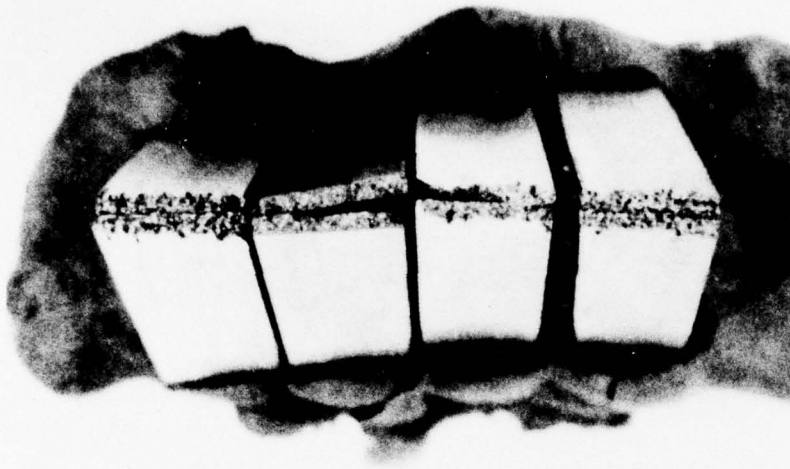
TENSILE RT 0°



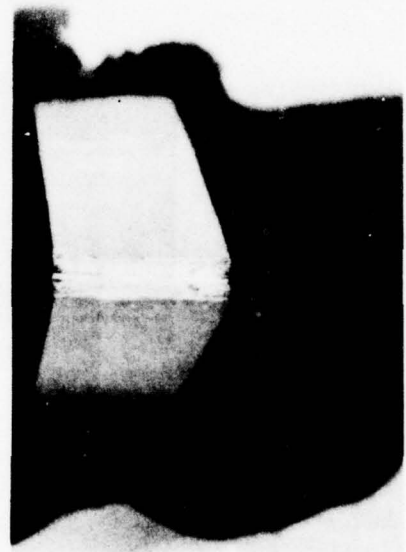
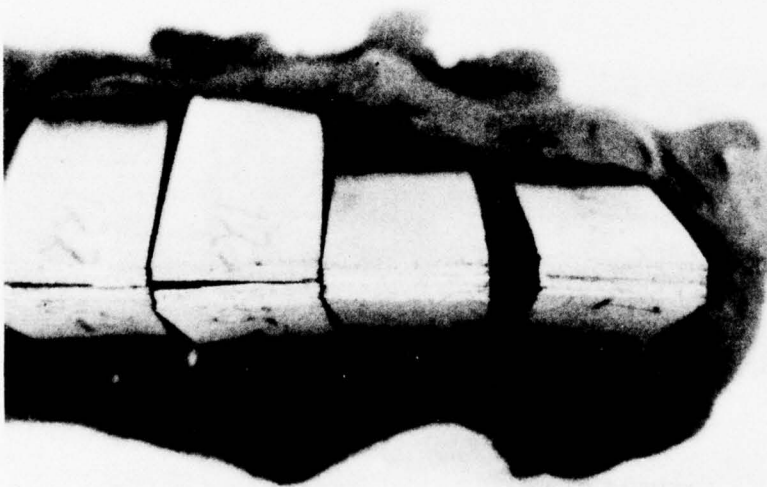
TENSILE RT 90°

FIGURE 34. 1100/5.6 MIL B/1100 CMC FIBER TENSILE SPECIMEN

1100/5.6 MIL B/1100 CMC FIBER



IMPACT RT 0°



IMPACT RT 90°

FIGURE 35. 1100/5.6 MIL B/1100 CMC FIBER TENSILE SPECIMEN

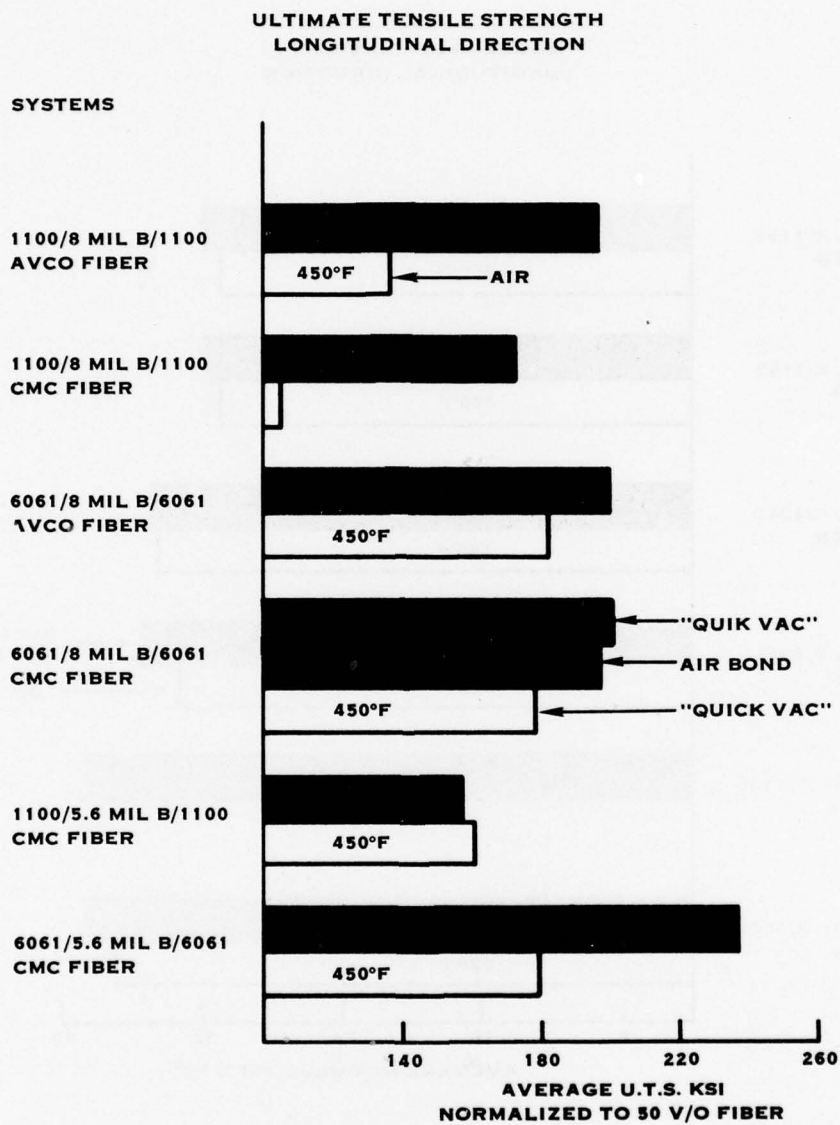


FIGURE 36. AVERAGE ULTIMATE TENSILE STRENGTH PROPERTIES FOR THE LONGITUDINAL DIRECTION AT ROOM TEMPERATURE (SOLID BARS) AND 450°F (OPEN BARS)

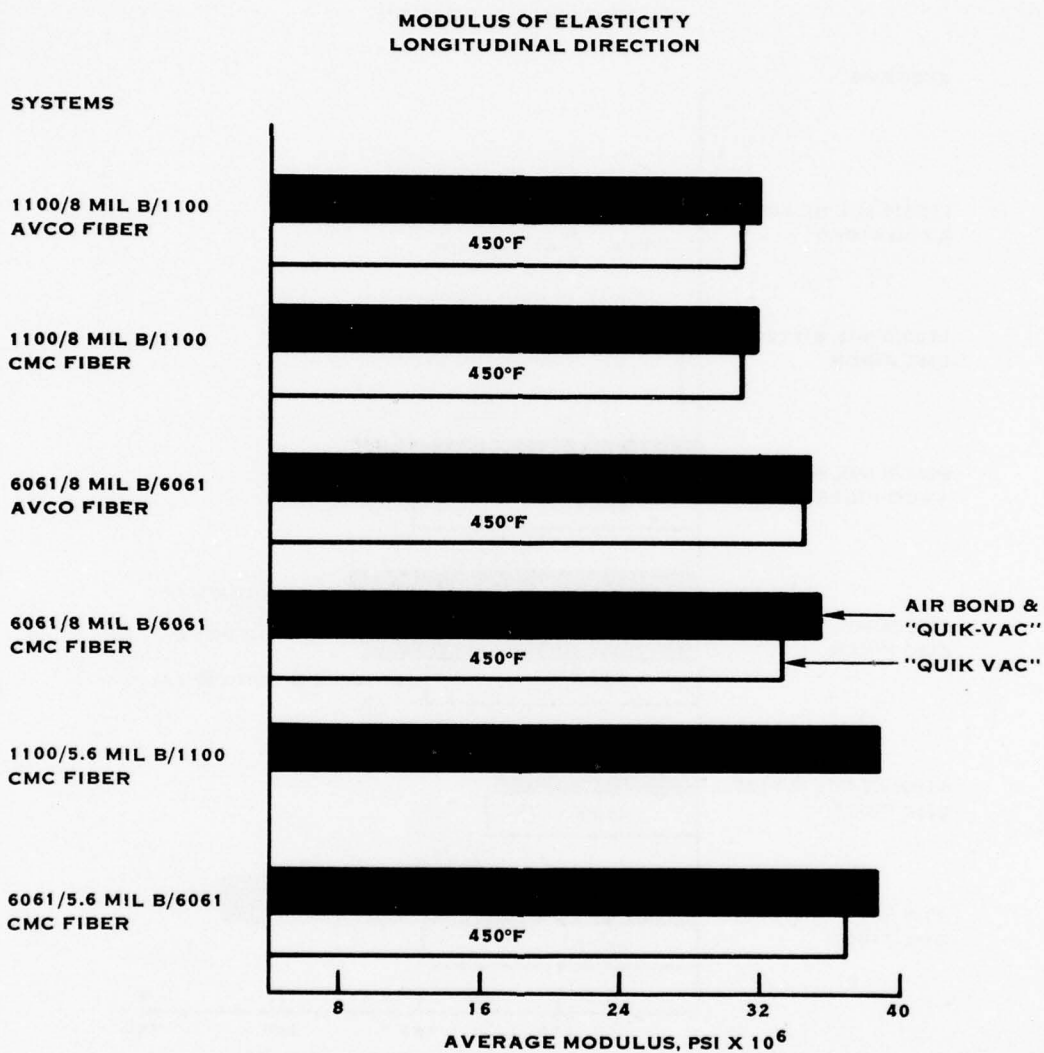


FIGURE 37. AVERAGE MODULUS OF ELASTICITY PROPERTIES FOR THE LONGITUDINAL DIRECTION AT ROOM TEMPERATURE (SOLID BARS) AND 450°F (OPEN BARS)

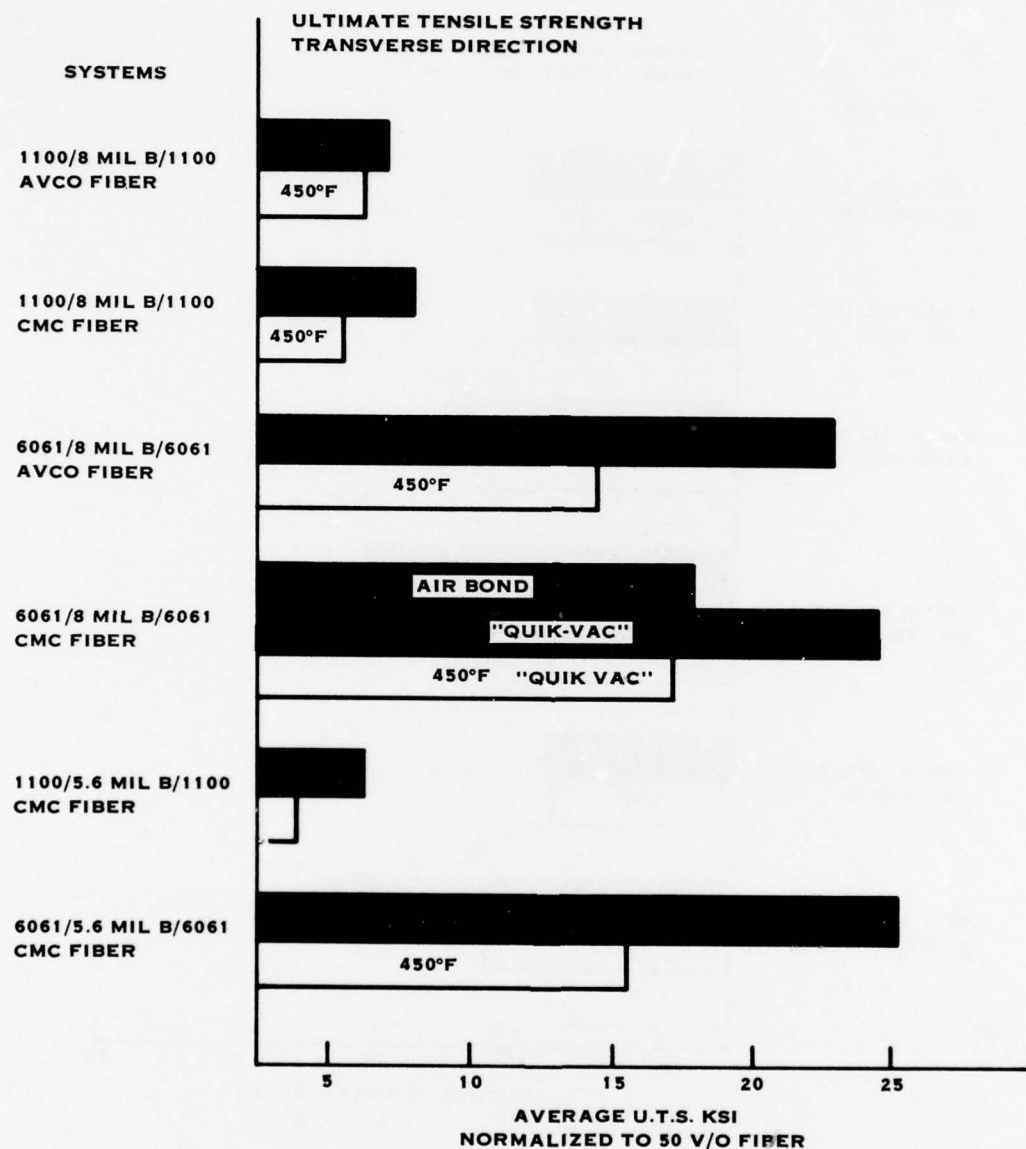


FIGURE 38. AVERAGE ULTIMATE TENSILE STRENGTH PROPERTIES FOR THE TRANSVERSE DIRECTION AT ROOM TEMPERATURE (SOLID BARS) AND 450°F (OPEN BARS)

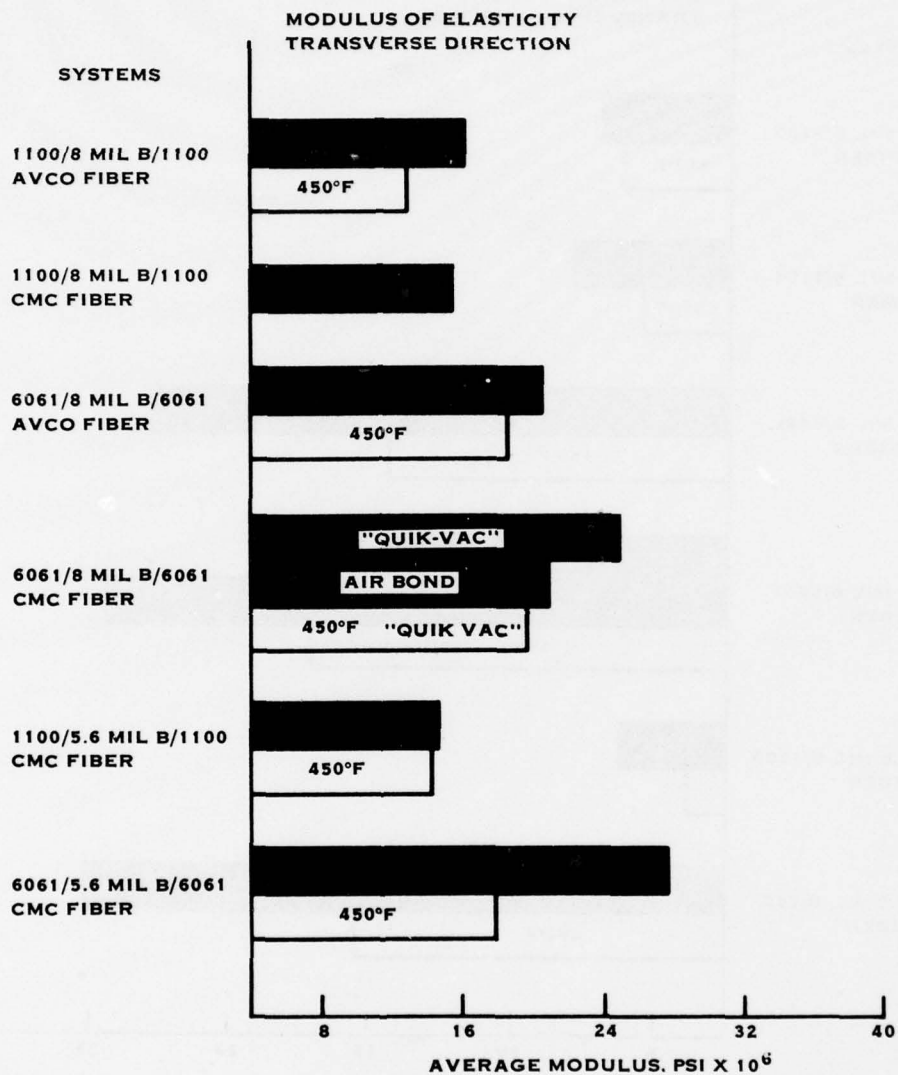


FIGURE 39. AVERAGE MODULUS OF ELASTICITY PROPERTIES FOR THE TRANSVERSE DIRECTION AT ROOM TEMPERATURE (SOLID BARS) AND 450°F (OPEN BARS)

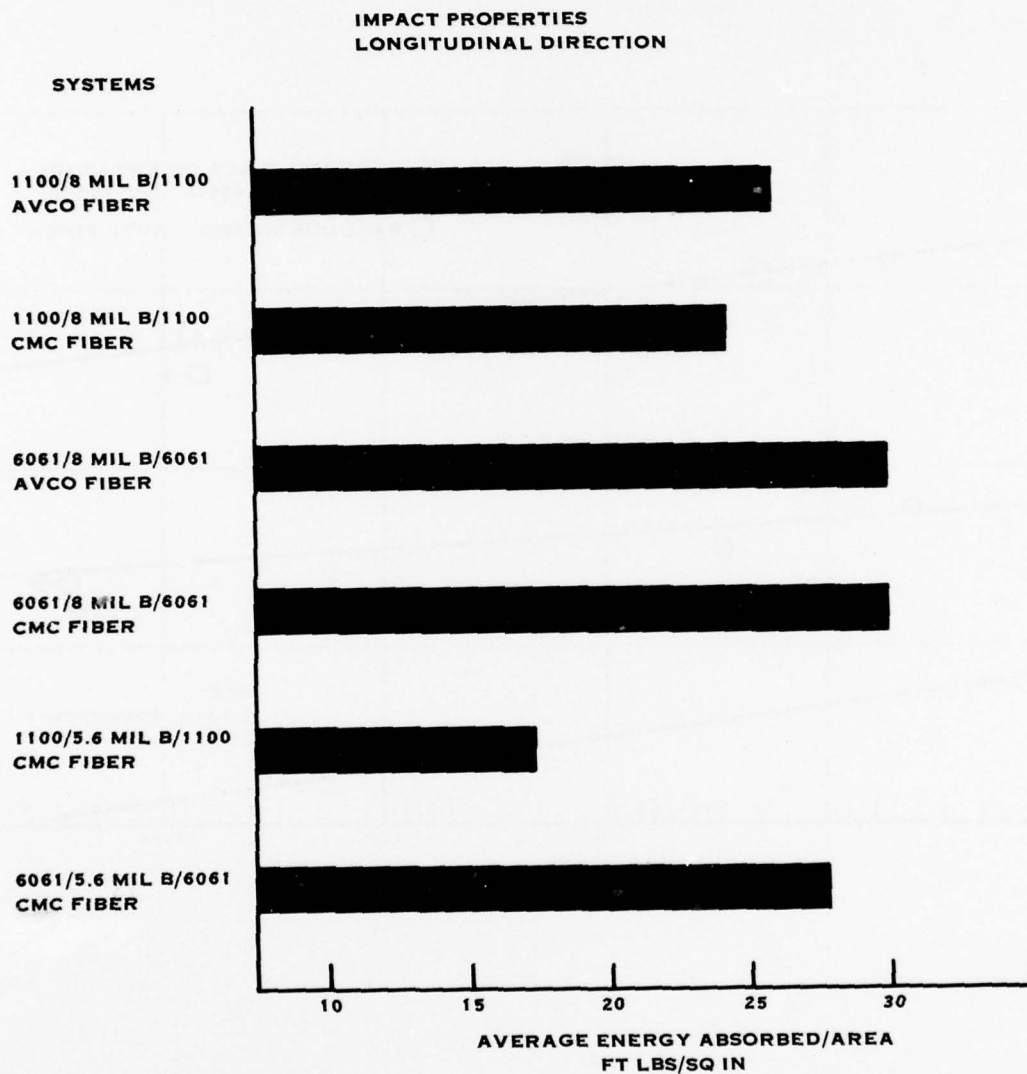


FIGURE 40. IMPACT ENERGY ABSORBED PER UNIT AREA

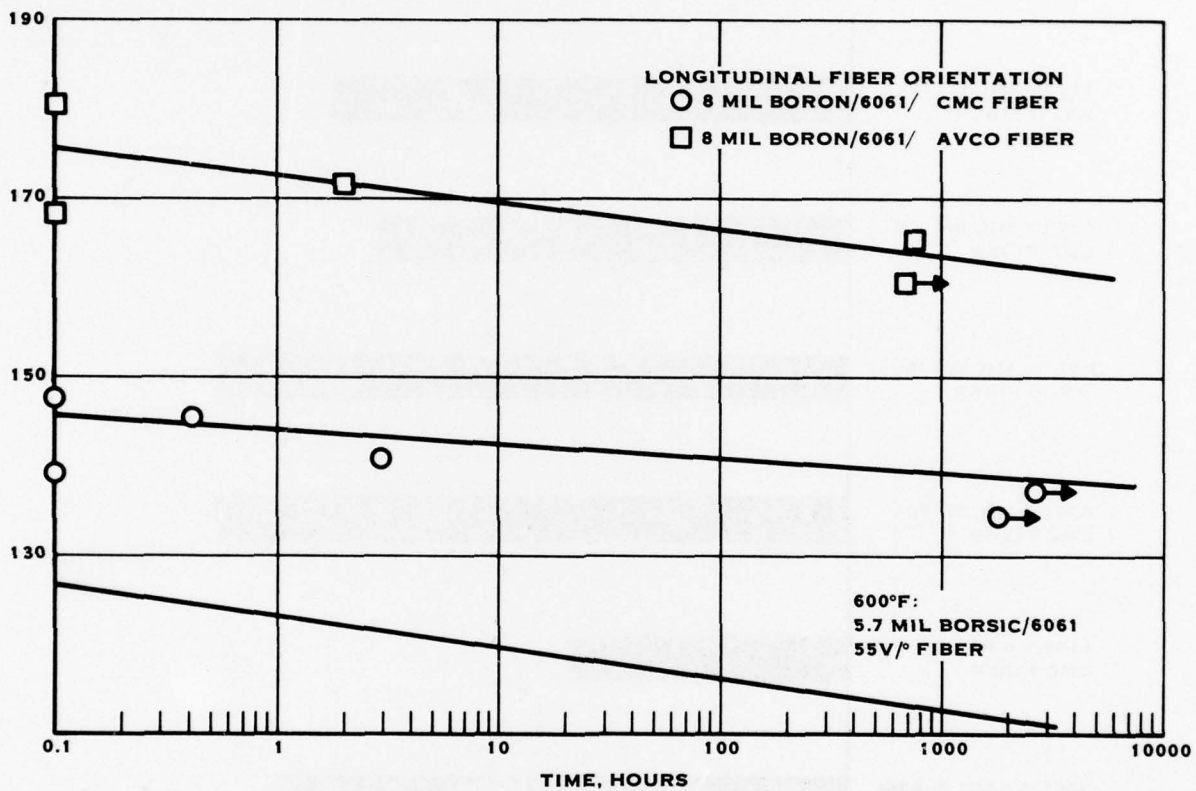


FIGURE 41. 450°F LONGITUDINAL STRESS RUPTURE PROPERTIES

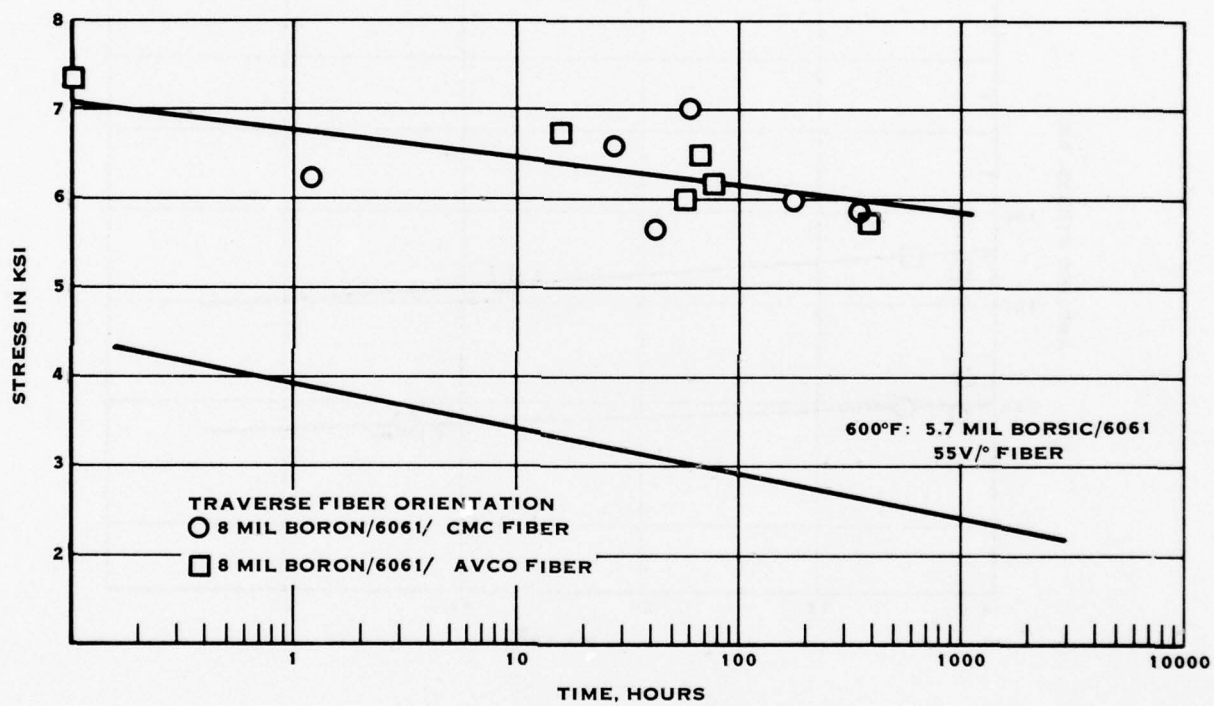
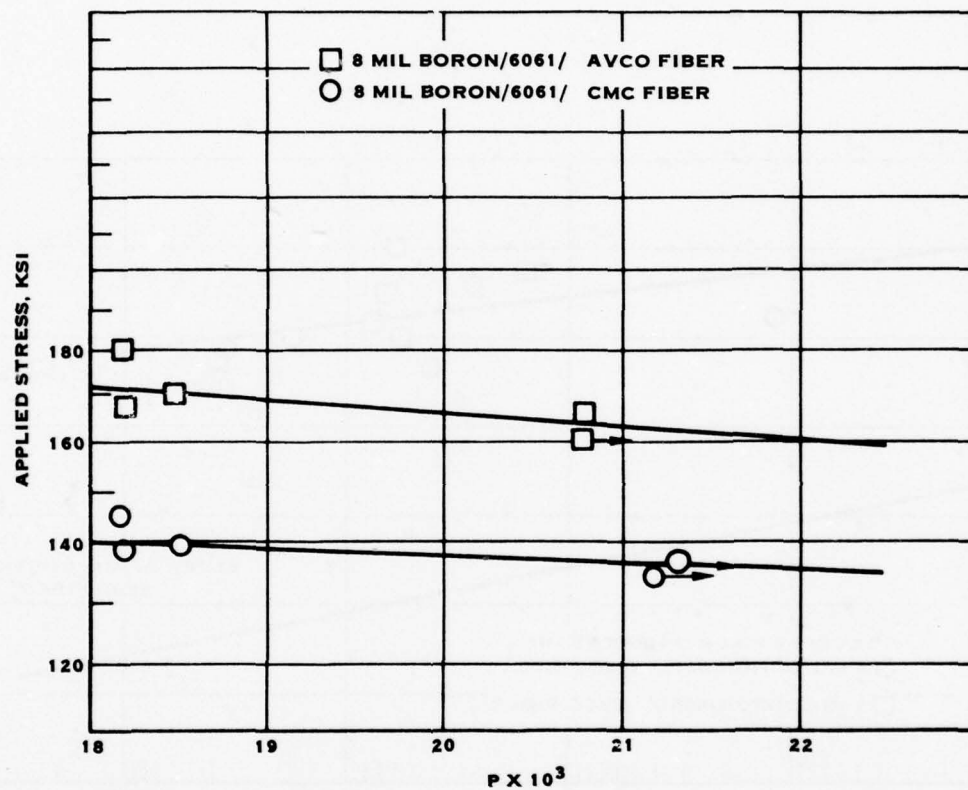


FIGURE 42. 450°F TRANSVERSE STRESS RUPTURE PROPERTIES



$$P = (T + 460) (20 + \text{LOG TIME})$$

$$T = ^\circ\text{F}$$

FIGURE 43. LARSON-MILLER PLOT, LONGITUDINAL DIRECTION 450°F STRESS RUPTURE

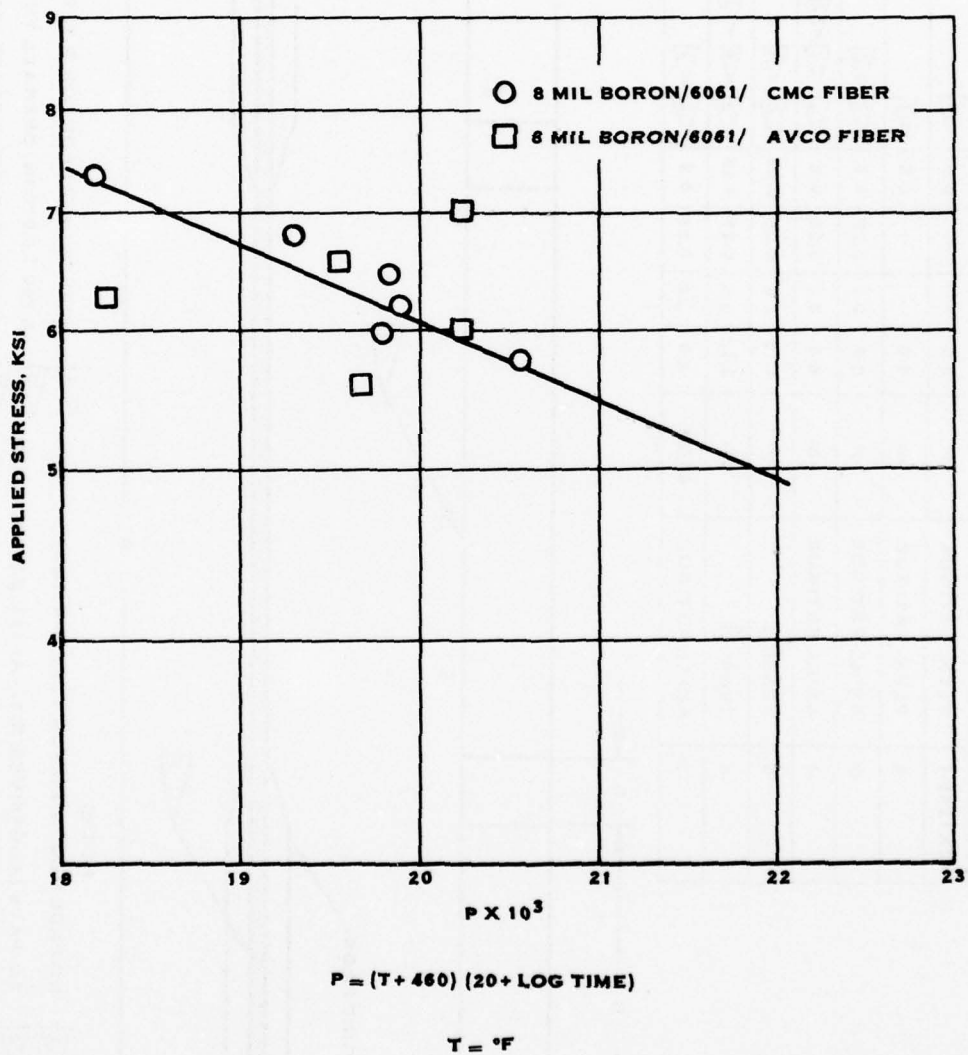
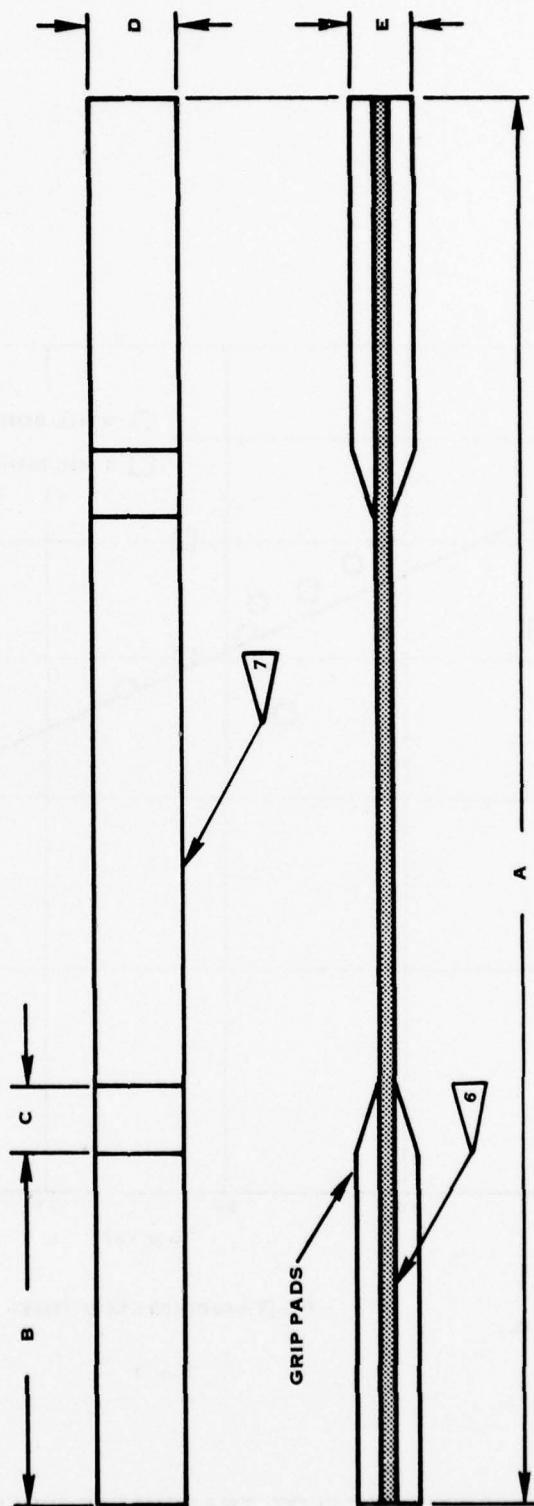


FIGURE 44. LARSON-MILLER PLOT, TRANSVERSE DIRECTION 450°F STRESS RUPTURE

DWG.	TEST MODE	FIBER ORIENT.	DIMENSIONS				
			A	B	C	D	E
12X1255-1	FLEX. FATIGUE	0°	8.0	—	—	0.5	1
-2	FLEX. FATIGUE	90°	6.0	—	—	0.5	1
-3	AXIAL FATIGUE	0°	8.0	2.0	0.25	0.5	2 3
-4	AXIAL FATIGUE	90°	6.0	2.0	0.25	0.5	2 3 4
-5	TENSILE	0°	4.75	2.0	0.25	0.25	2 3
-6	TENSILE	90°	2.12	0.5	0.25	0.25	2 4 5
-7	AXIAL FATIGUE	45/45	8.0	2.0	0.25	0.5	2 3



- NOTES
- 1 NO PADS REQUIRED FOR FLEX. FATIGUE
 - 2 AL. PADS (ADHESIVES: R.T. - AF111, E.T. - H.T. 424) (OR AS SPECIFIED)
 - 3 0.230 ± 0.003 IN. OVERALL THICKNESS
 - 4 FIBERGLASS PADS FOR R.T. TESTS
 - 5 0.300 ± 0.010 IN. OVERALL THICKNESS
 - 6 SANDBLAST INTERFACES BEFORE BONDING
 - 7 GENTLE EDGE BREAK - NO TOOL MARKS

FIGURE 45. FATIGUE TEST SPECIMEN

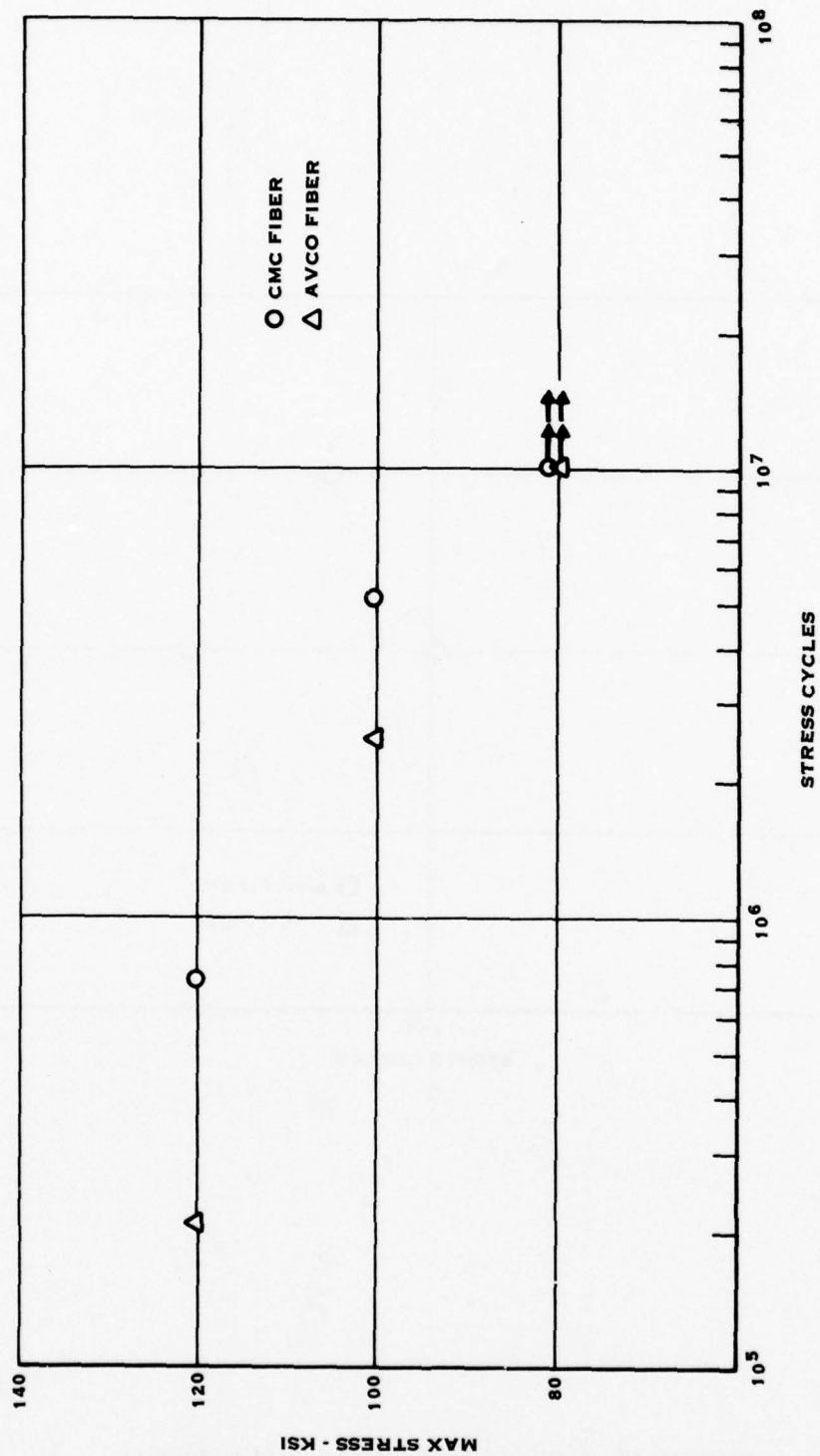


FIGURE 46. QUIK VAC SPECIMENS (8 MIL B/6061) AXIAL FATIGUE ($R = 0.1$) 0° FIBER ORIENTATION

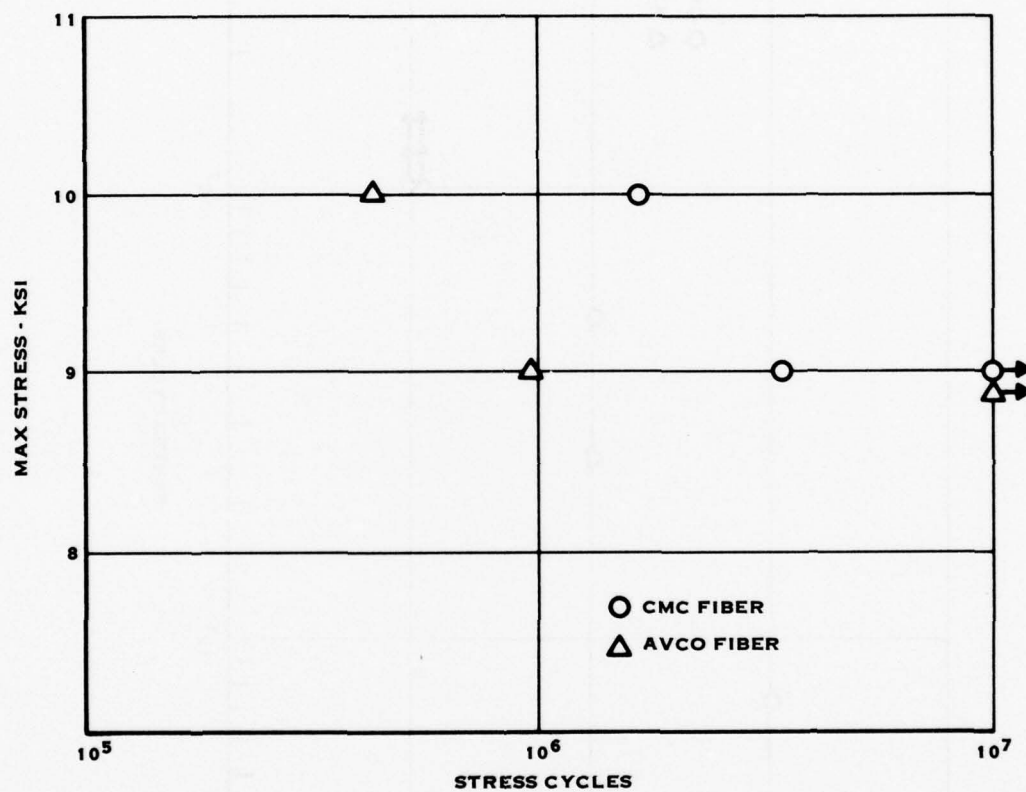


FIGURE 47. QUIK VAC SPECIMENS (8 MIL B/6061)
AXIAL FATIGUE (R = 0.1) 90° FIBER ORIENTATION

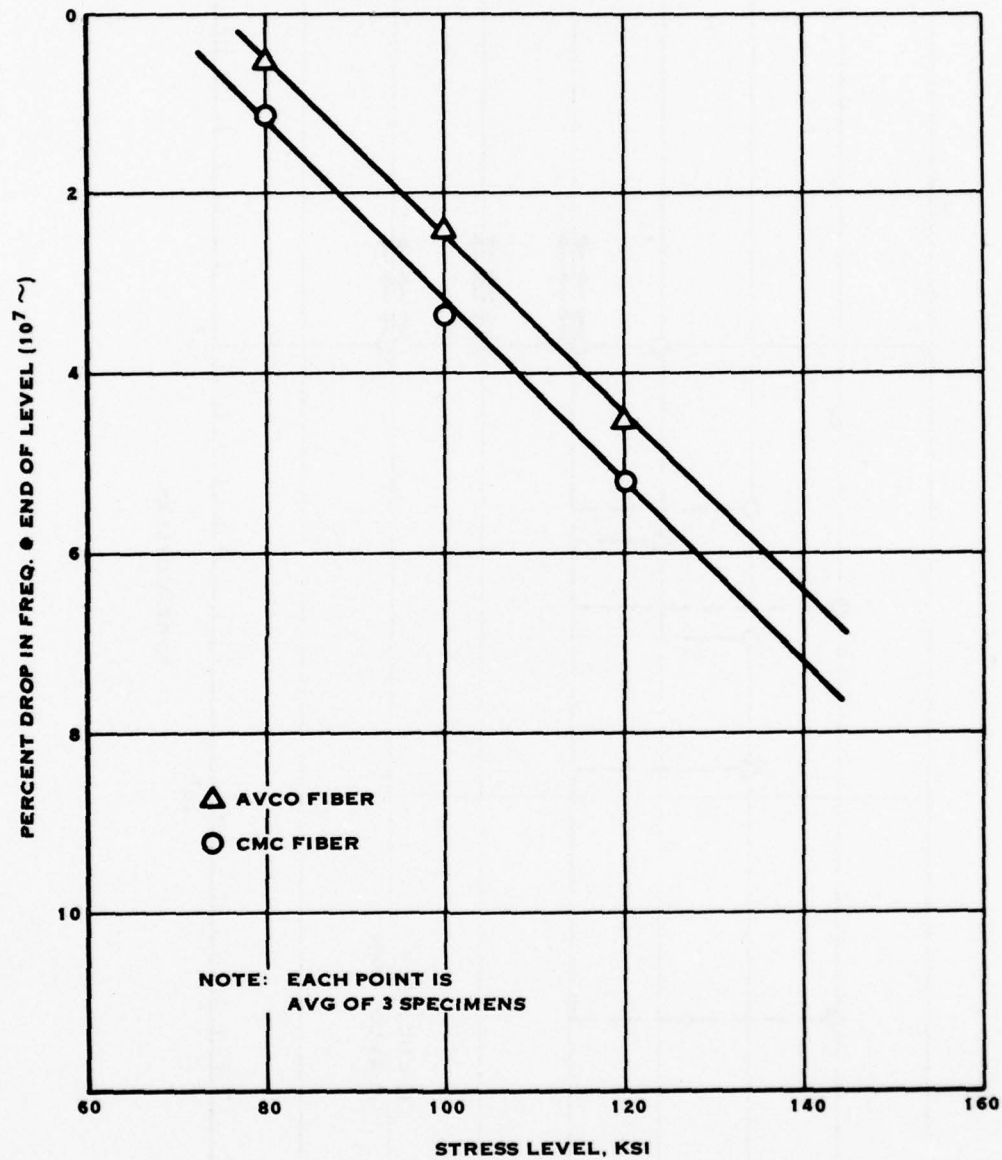


FIGURE 48. QUIK VAC SPECIMEN DATA 8 MIL B/6061 (0° FIBER ORIENTATION)
FLEXURAL FATIGUE $R = -1$

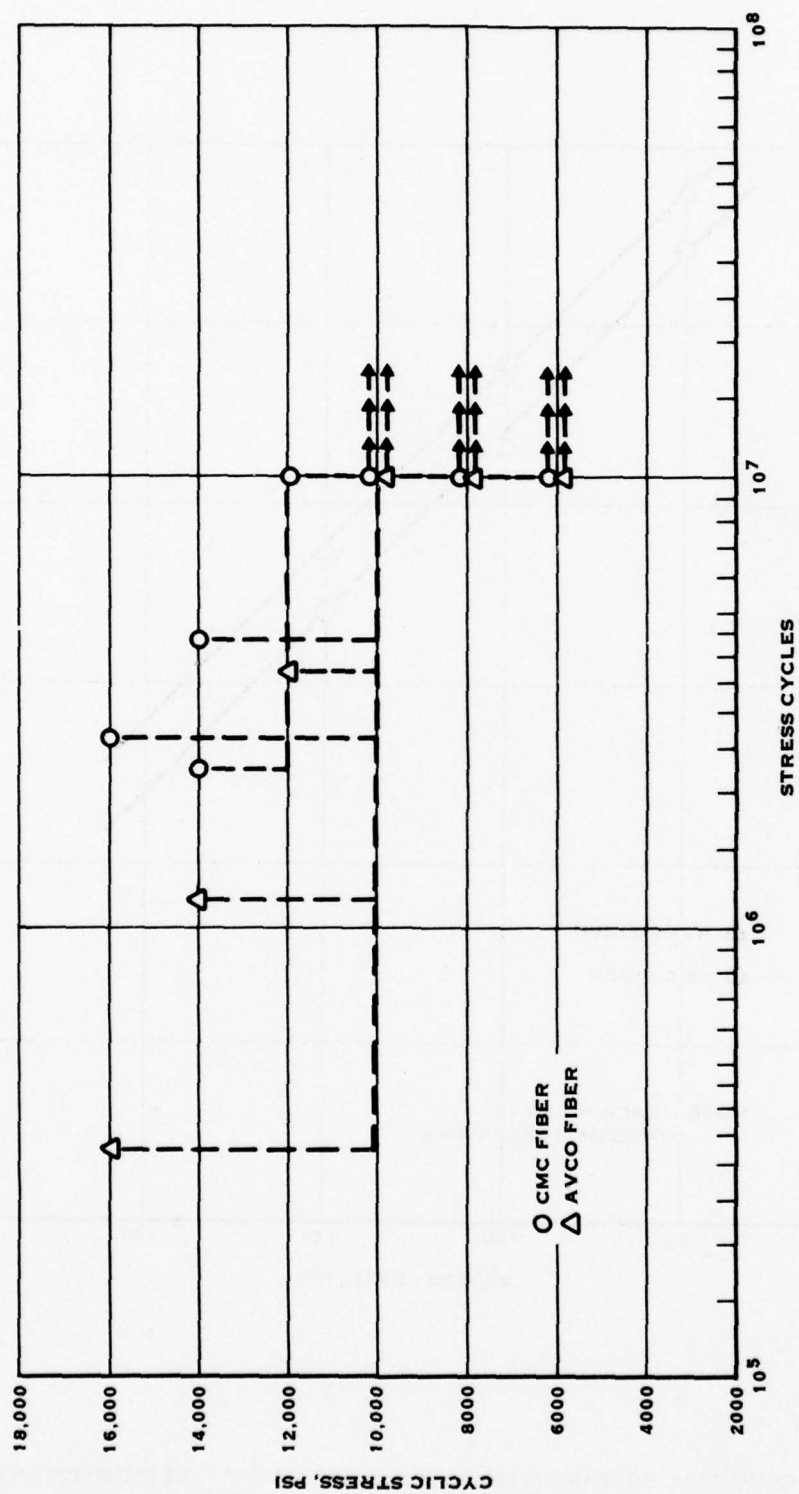


FIGURE 49. QUIK VAC SPECIMENS (8 MIL. B/6061) 90° FIBER ORIENTATION FLEXURAL FATIGUE TEST DATA (R = -1)

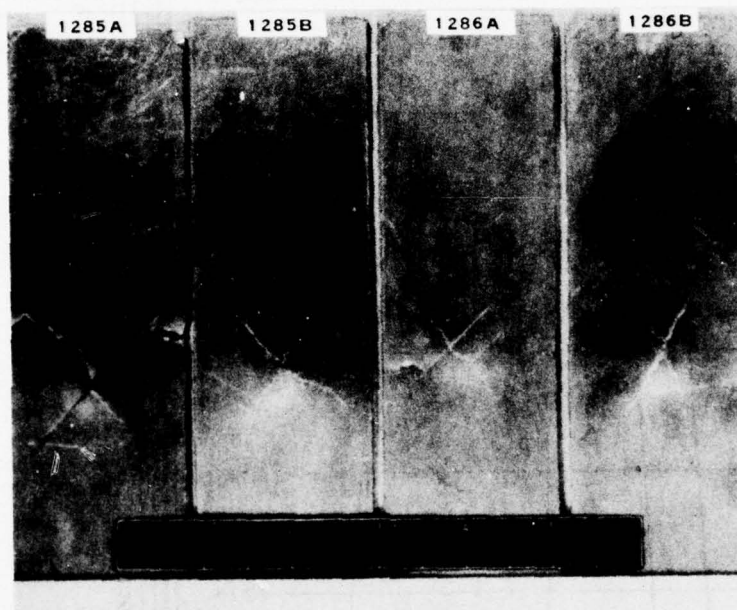


FIGURE 50. BACK SURFACE OF IMPACTED SPECIMENS

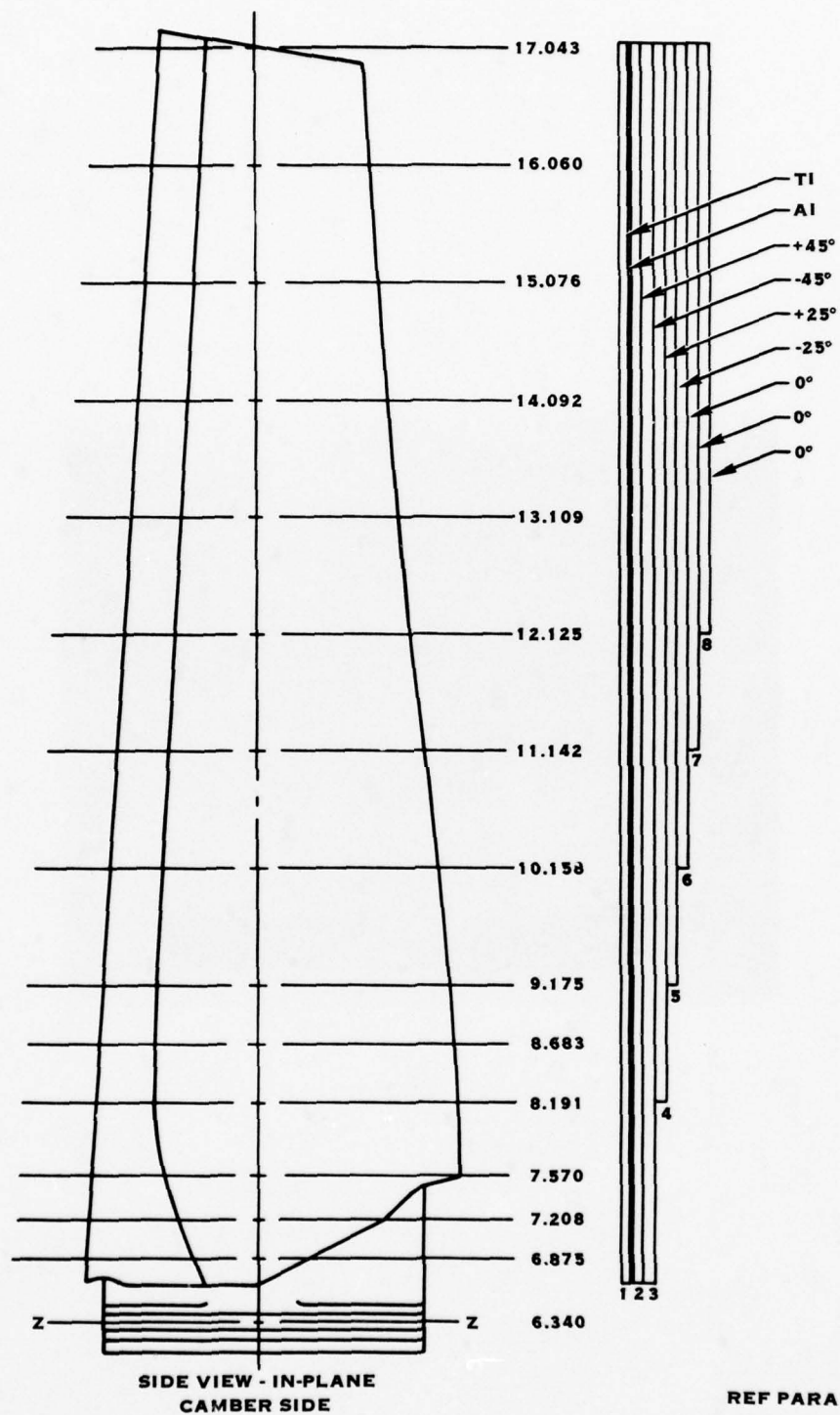


FIGURE 51. SCHEMATIC OF SHELL PLY ORIENTATION CAMBER SIDE
FABRICATION DEMONSTRATION

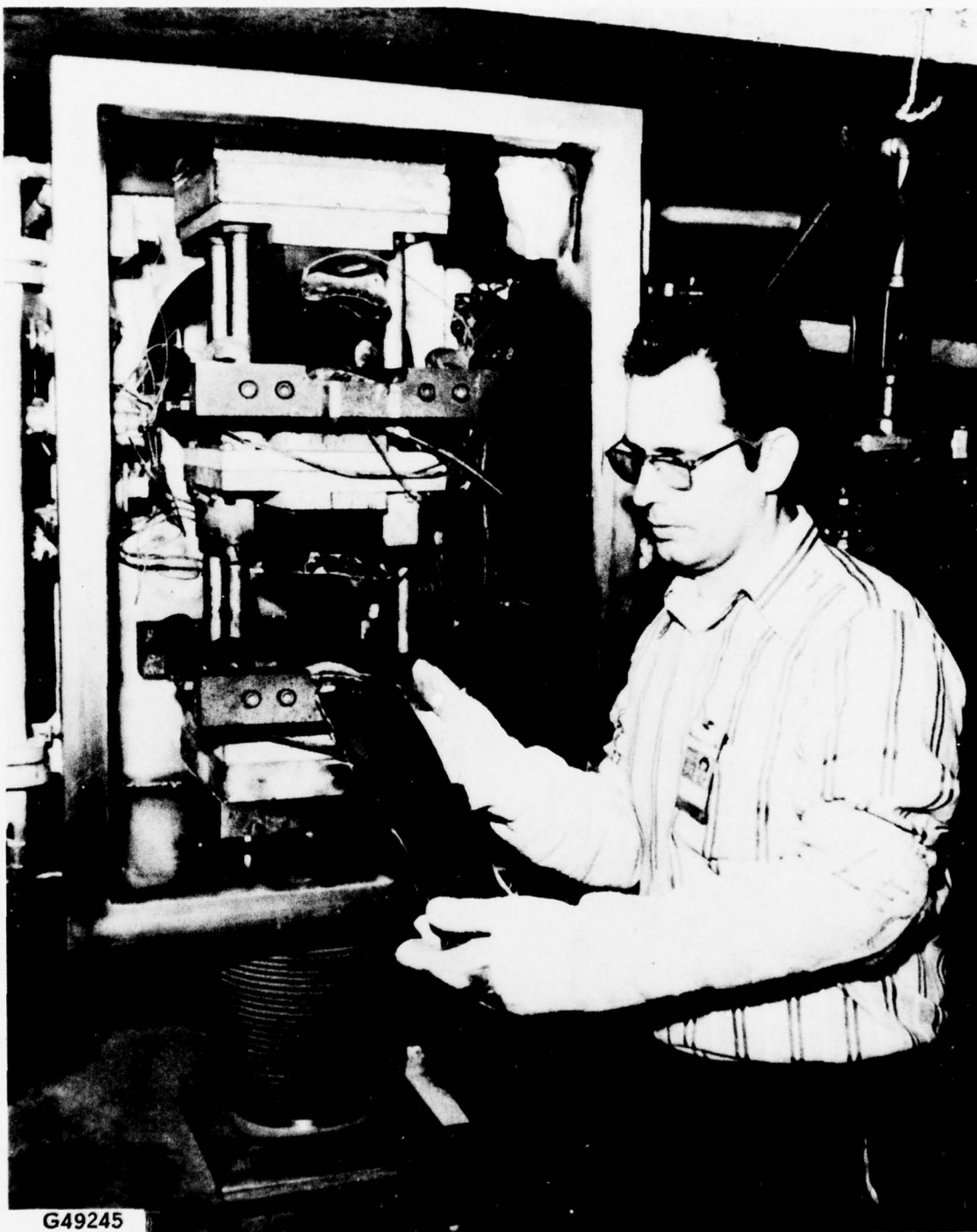
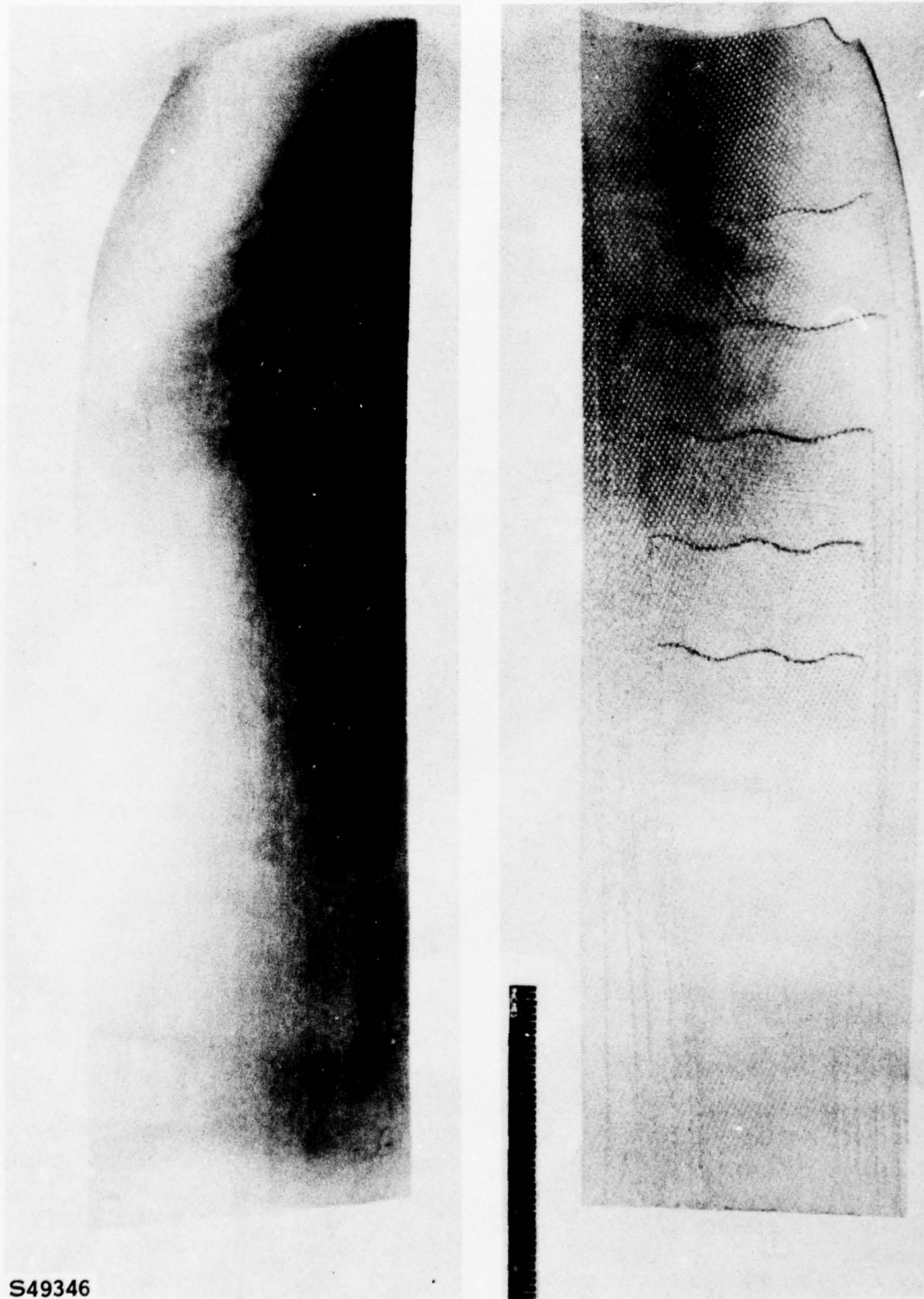
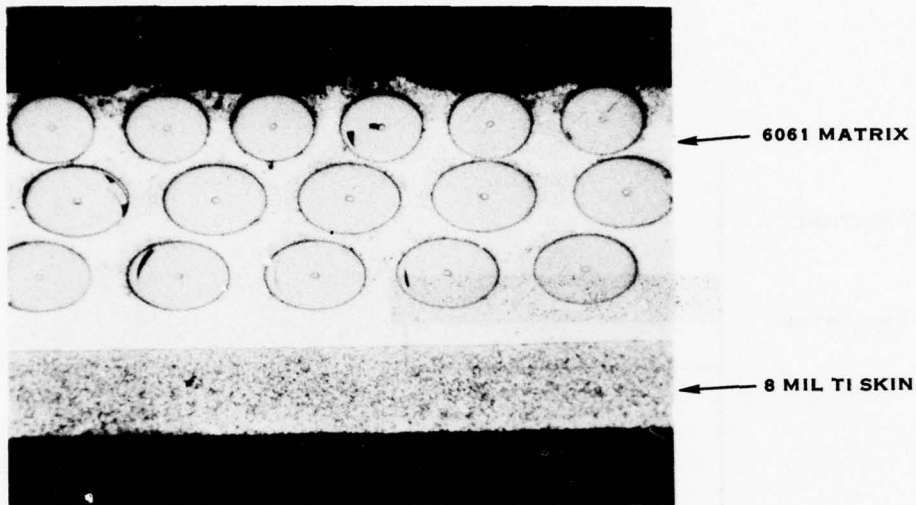


FIGURE 52. SHELL LAYUP WITH 8 MIL BORON 6061 ALUMINUM
READY FOR "QUIK VAC" BONDING



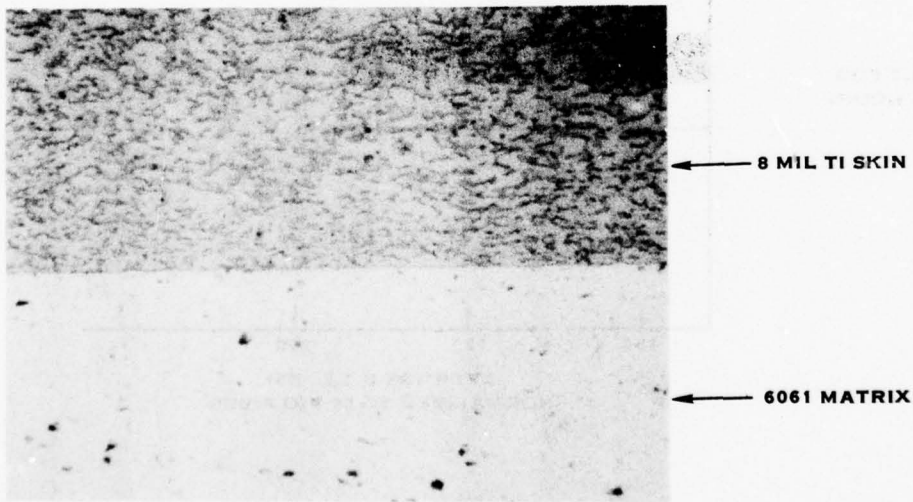
S49346

FIGURE 53. QUIK VAC BONDED F-100 CAMBER SHELL



(A)

BLADE SHELL SECTION WITH 8 MIL
AVCO BORON AND 6061 ALUMINUM
MATRIX WITH TI 6 AL - 4V SKIN



(B)

INTERFACE BETWEEN TI 6 AL - 4V
SKIN AND 6061 ALUMINUM MATRIX

FIGURE 54.

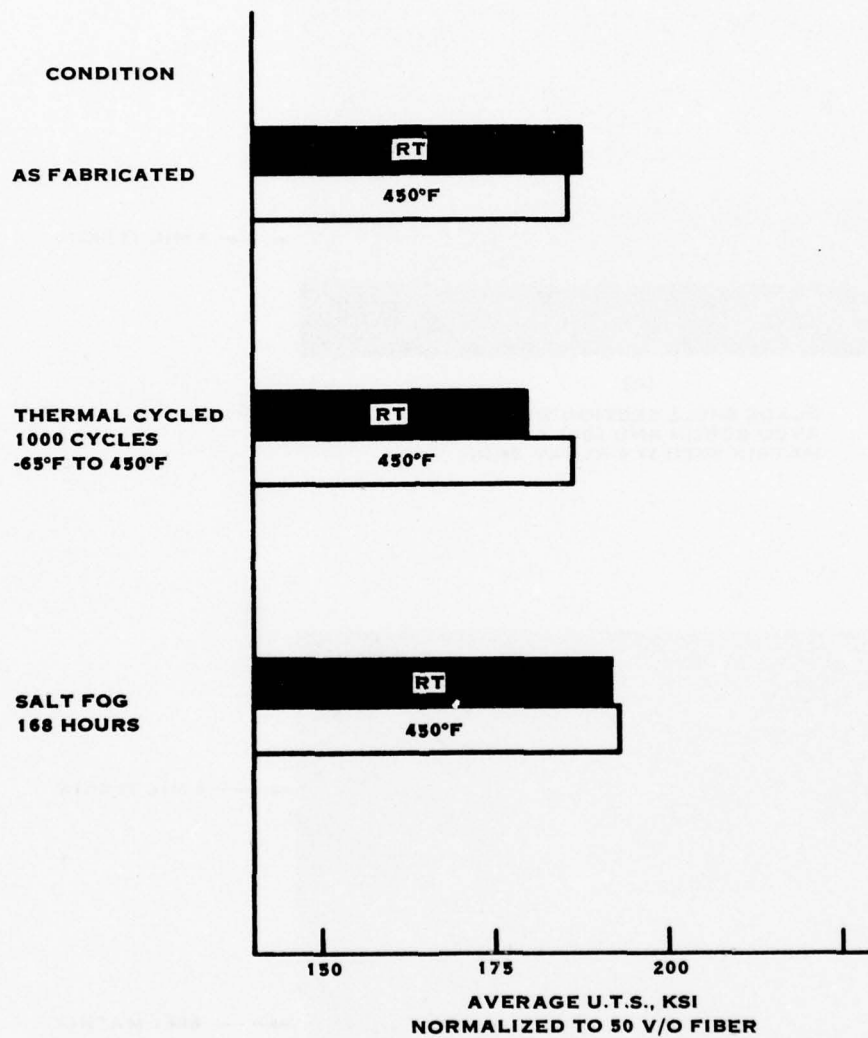


FIGURE 55. RT AND 450°F ULTIMATE TENSILE STRENGTH LONGITUDINAL DIRECTION
6061/8 MIL/CMC FIBER

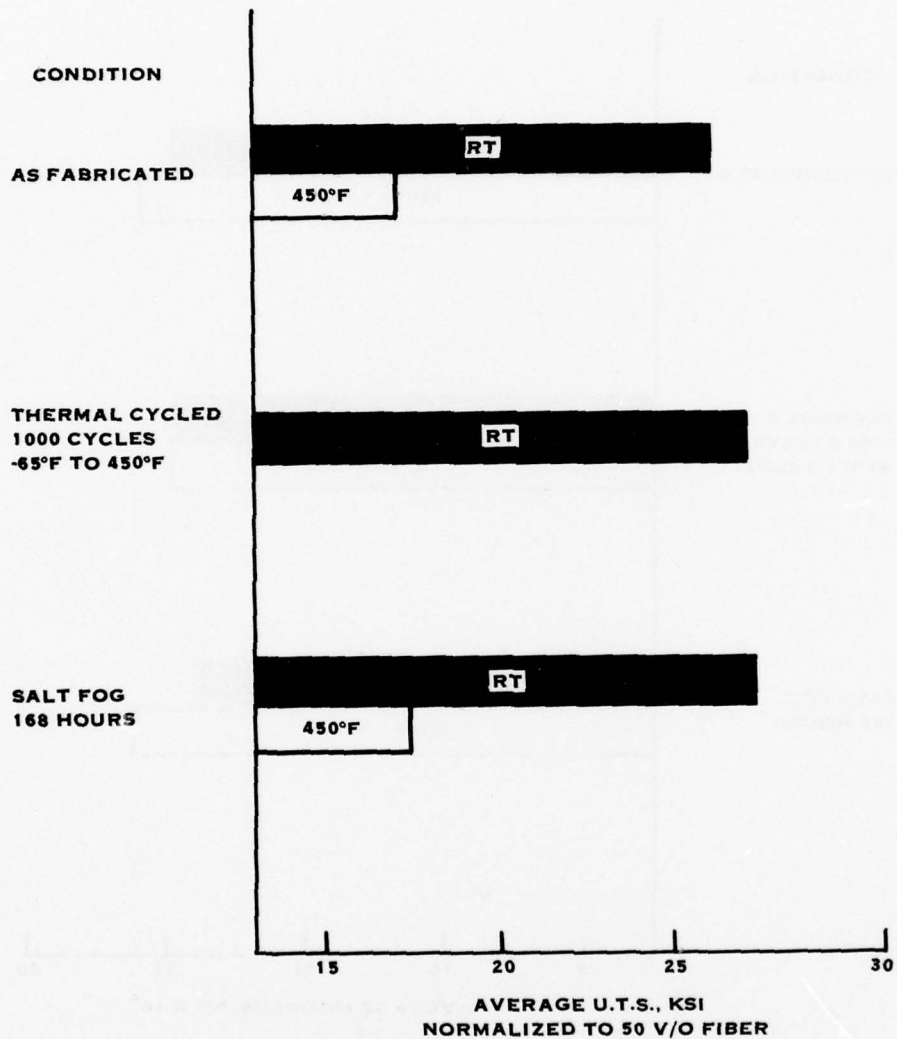


FIGURE 56. RT AND 450°F ULTIMATE TENSILE STRENGTH TRANSVERSE DIRECTION
6061/8 MIL/CMC FIBER

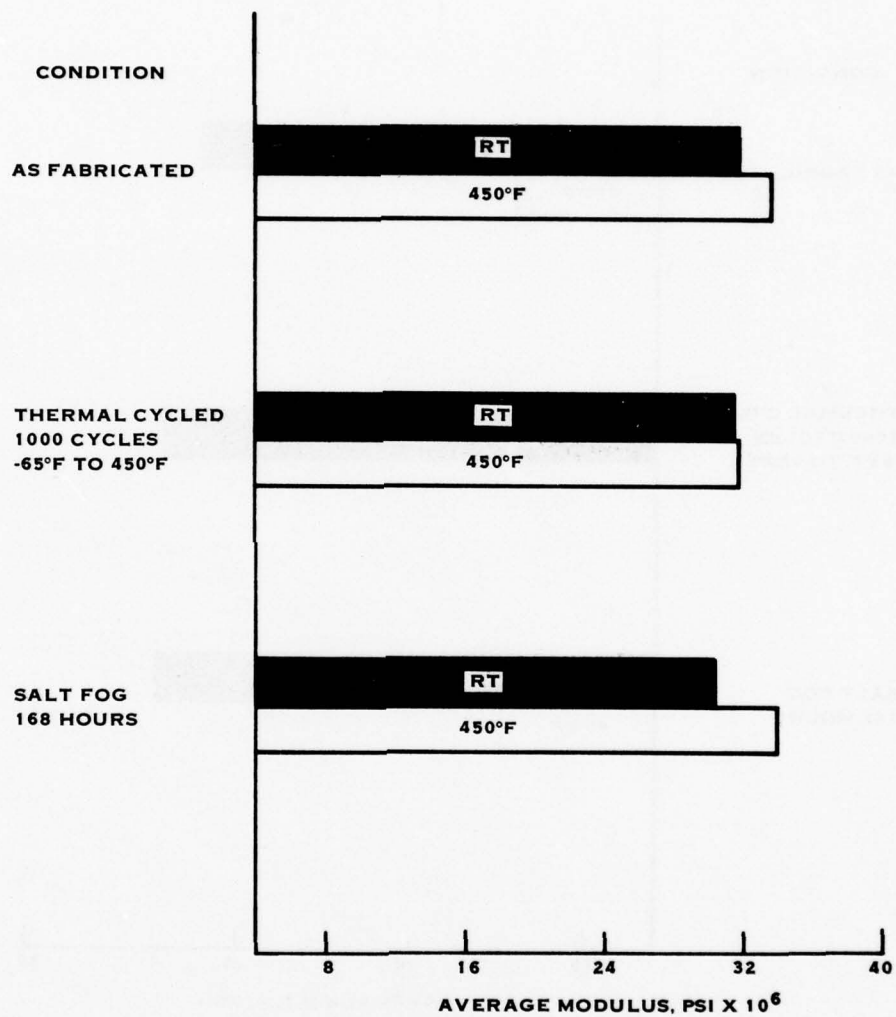


FIGURE 57. RT AND 450°F MODULUS OF ELASTICITY LONGITUDINAL DIRECTION
6061/8 MIL/CMC FIBER

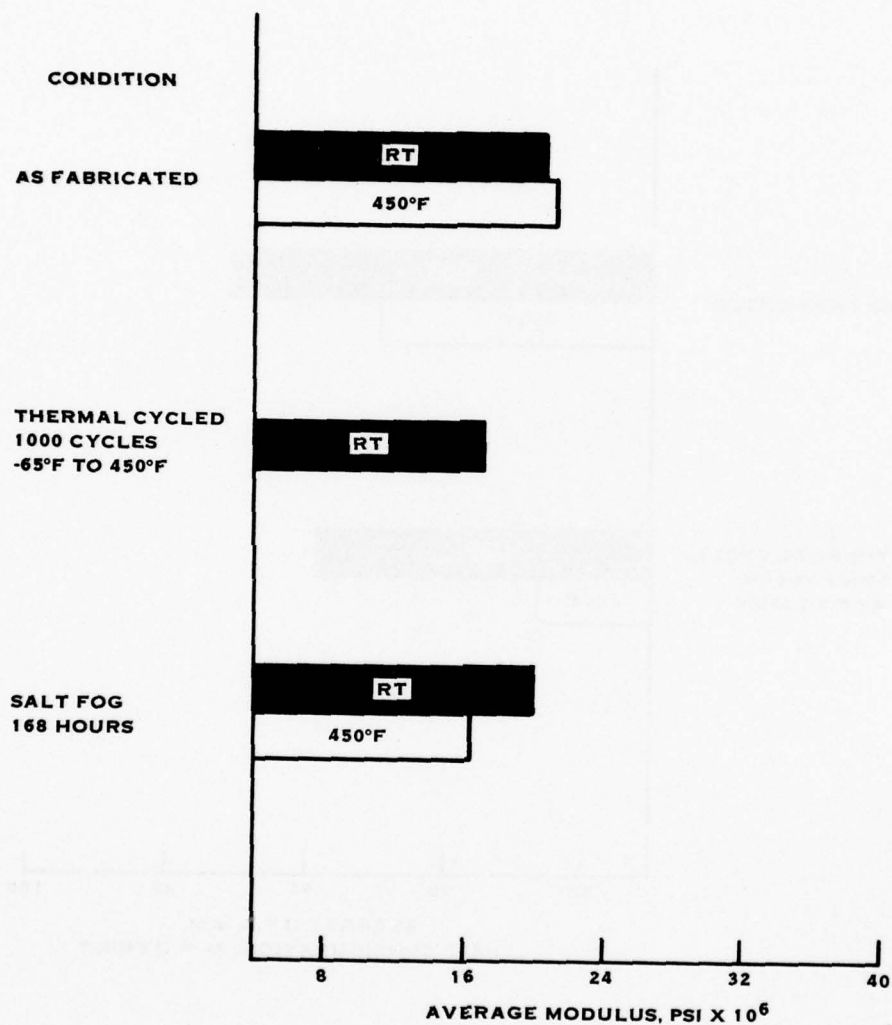


FIGURE 58. RT AND 450°F MODULUS OF ELASTICITY TRANSVERSE DIRECTION
6061/8 MIL/CMC FIBER

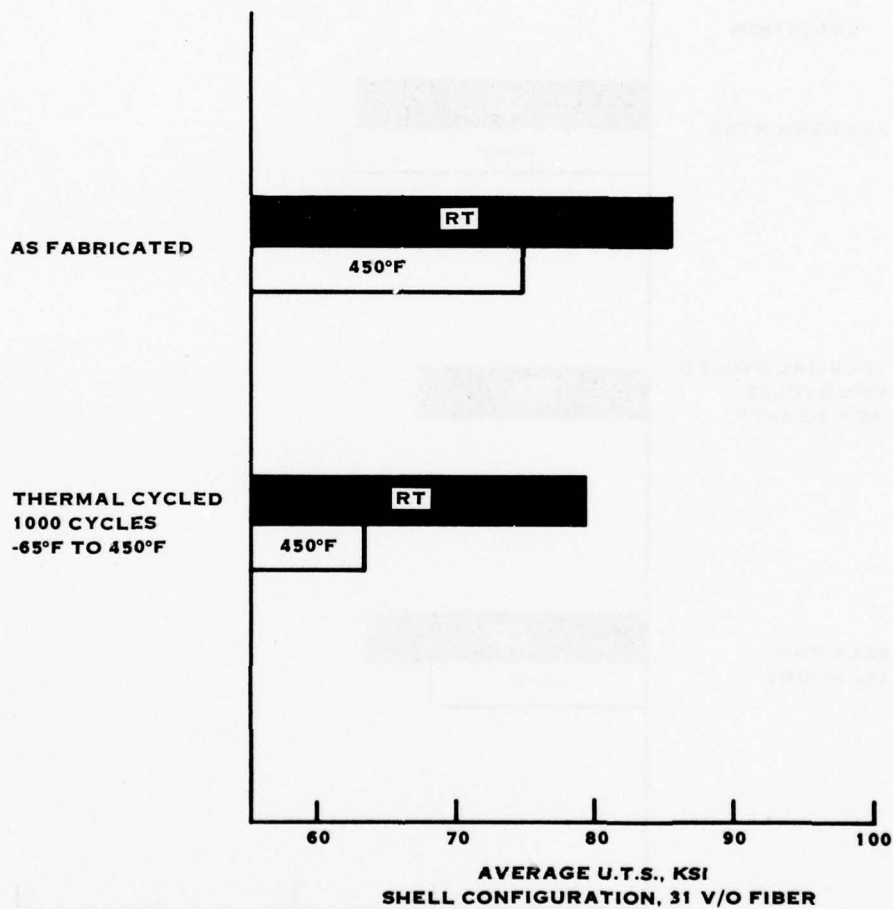


FIGURE 59. R.T. AND 450°F ULTIMATE TENSILE STRENGTH BLADE SHELL CONFIGURATION AXIAL DIRECTION 6061/8 MIL/CMC/FIBER

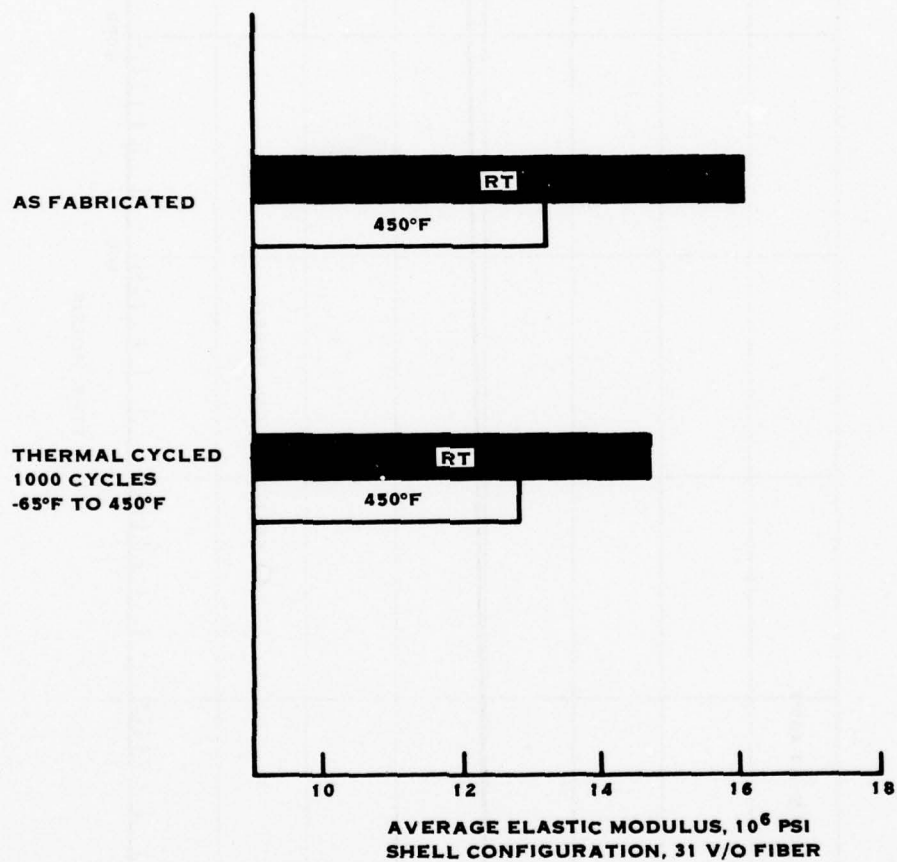


FIGURE 60. R.T. AND 450°F MODULUS OF ELASTICITY BLADE SHELL CONFIGURATION
AXIAL DIRECTION 6061/8 MIL/CMC FIBER

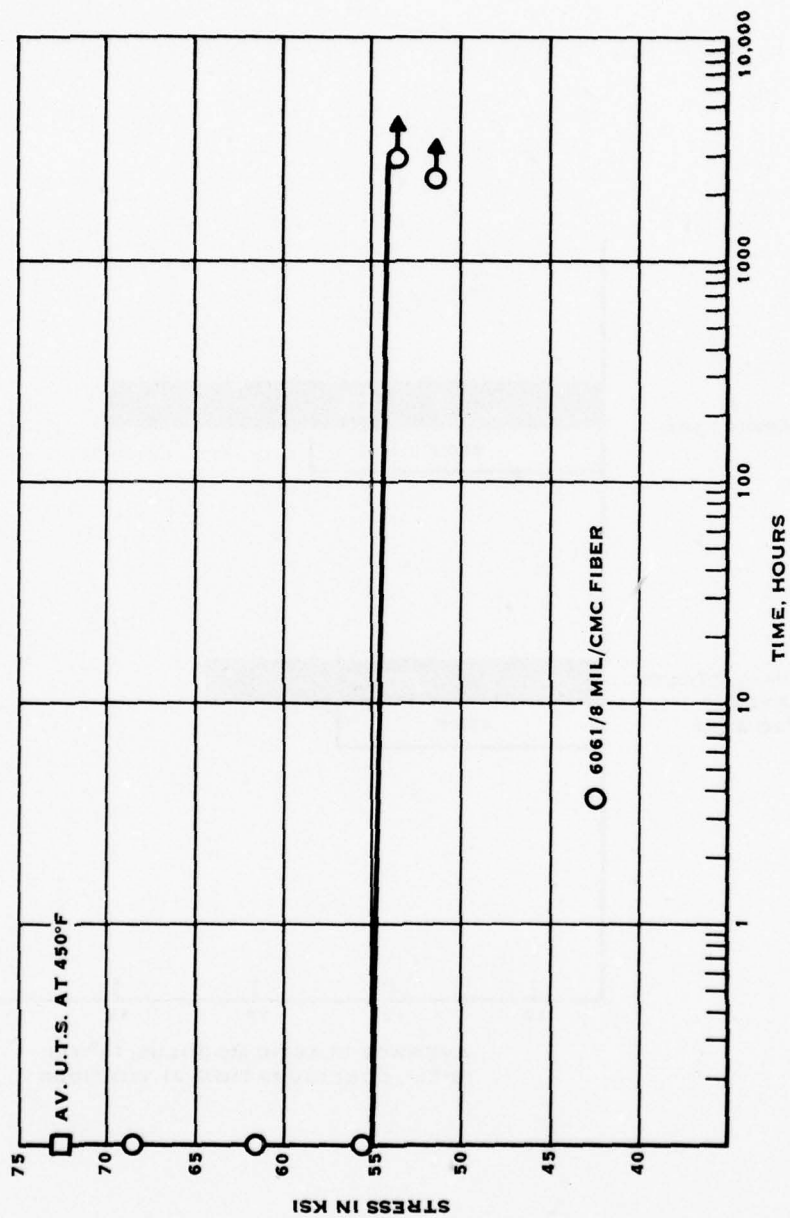


FIGURE 61. 450°F STRESS RUPTURE PROPERTIES SHELL CONFIGURATION

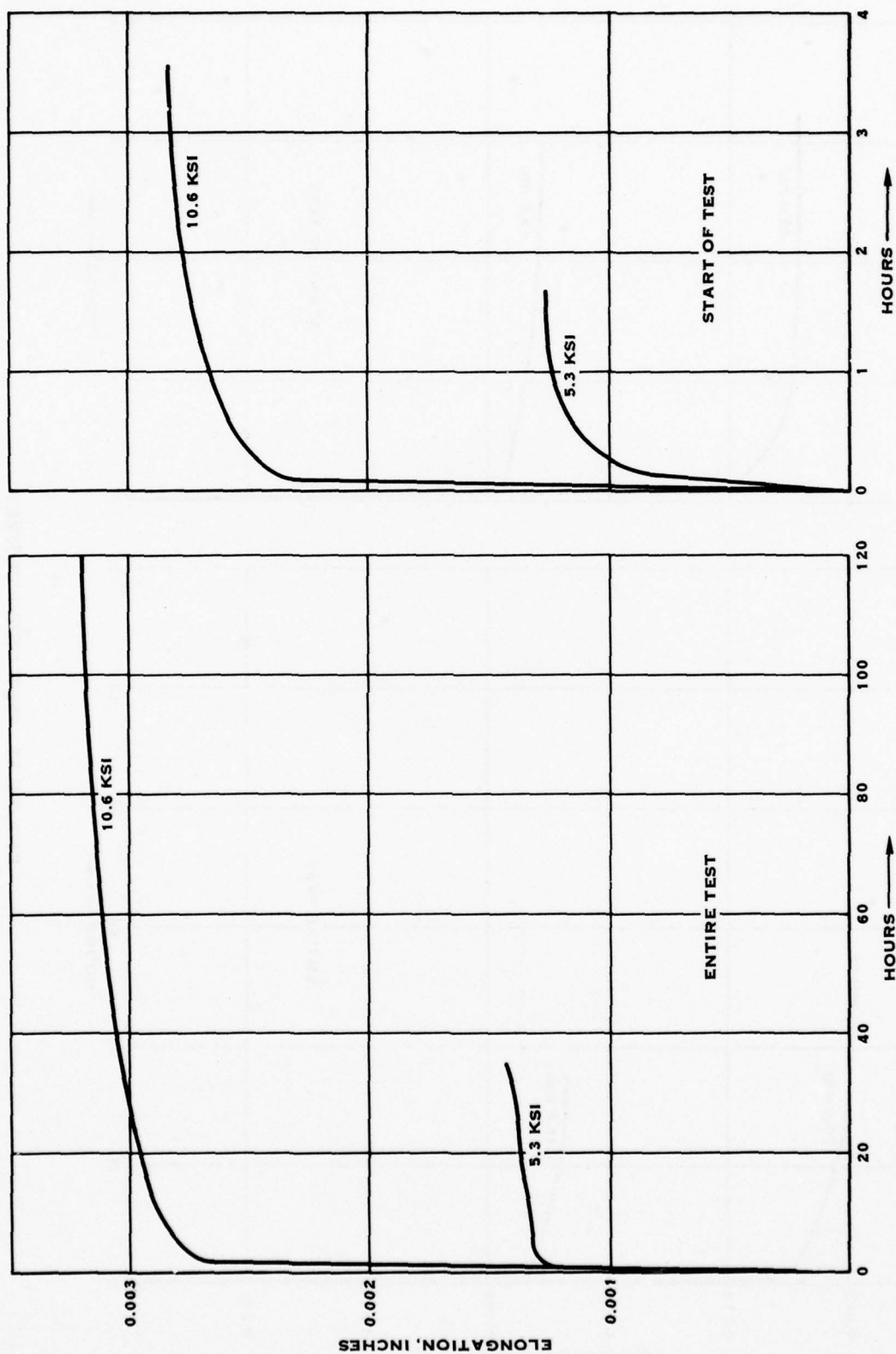


FIGURE 62. 450°F CREEP CURVES

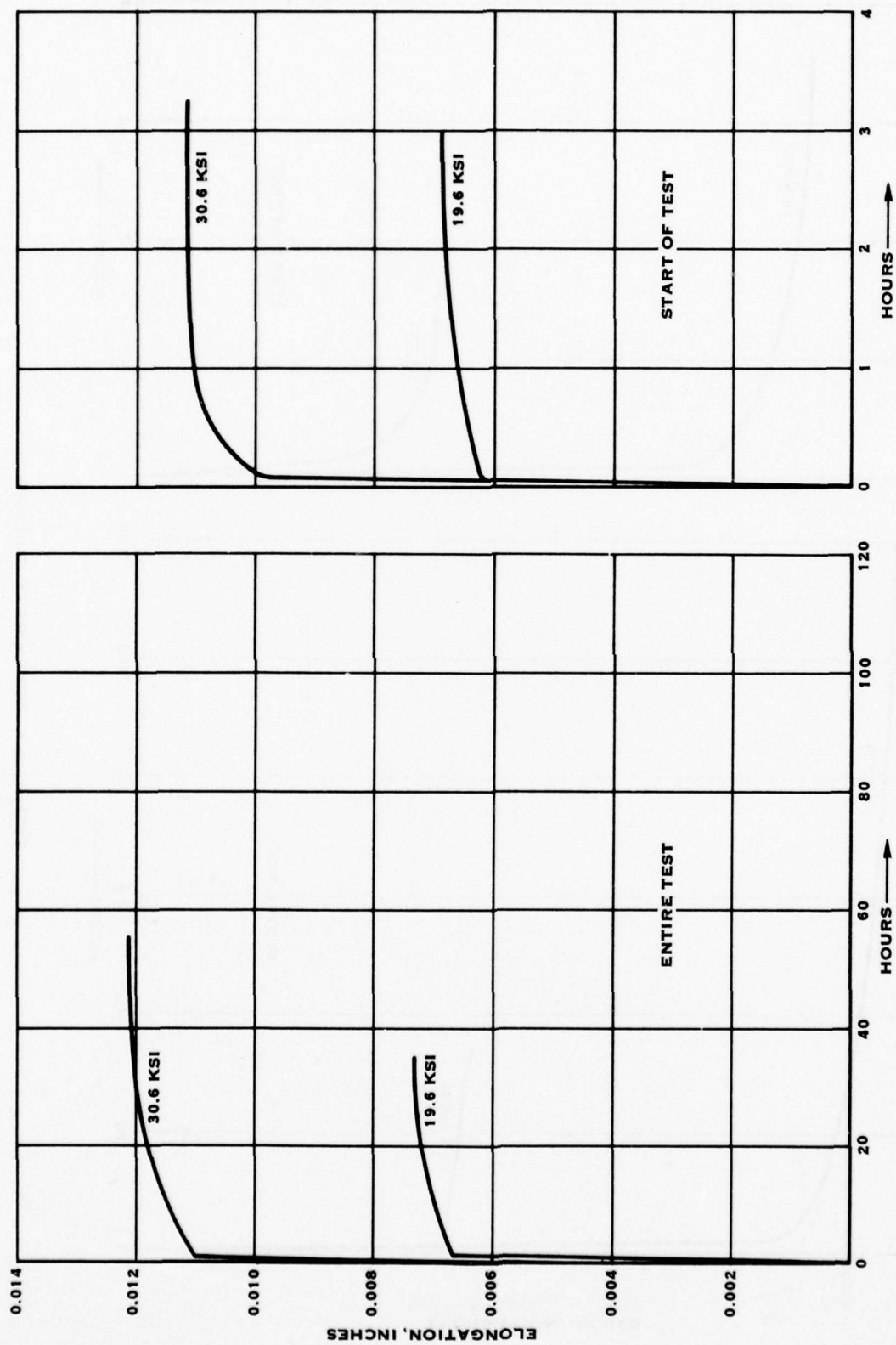


FIGURE 63. 450°F CREEP CURVES

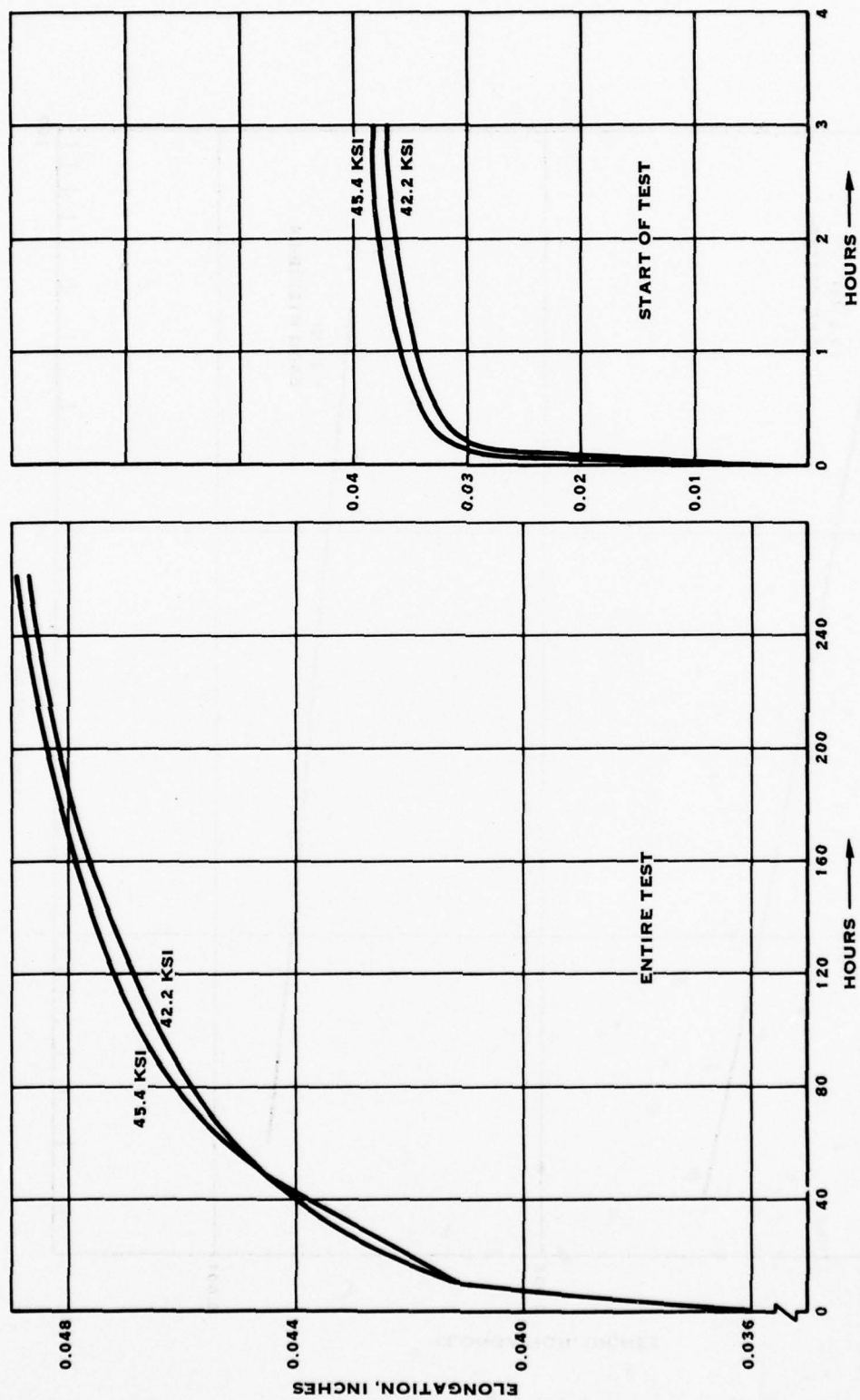


FIGURE 64. 450°F CREEP CURVES

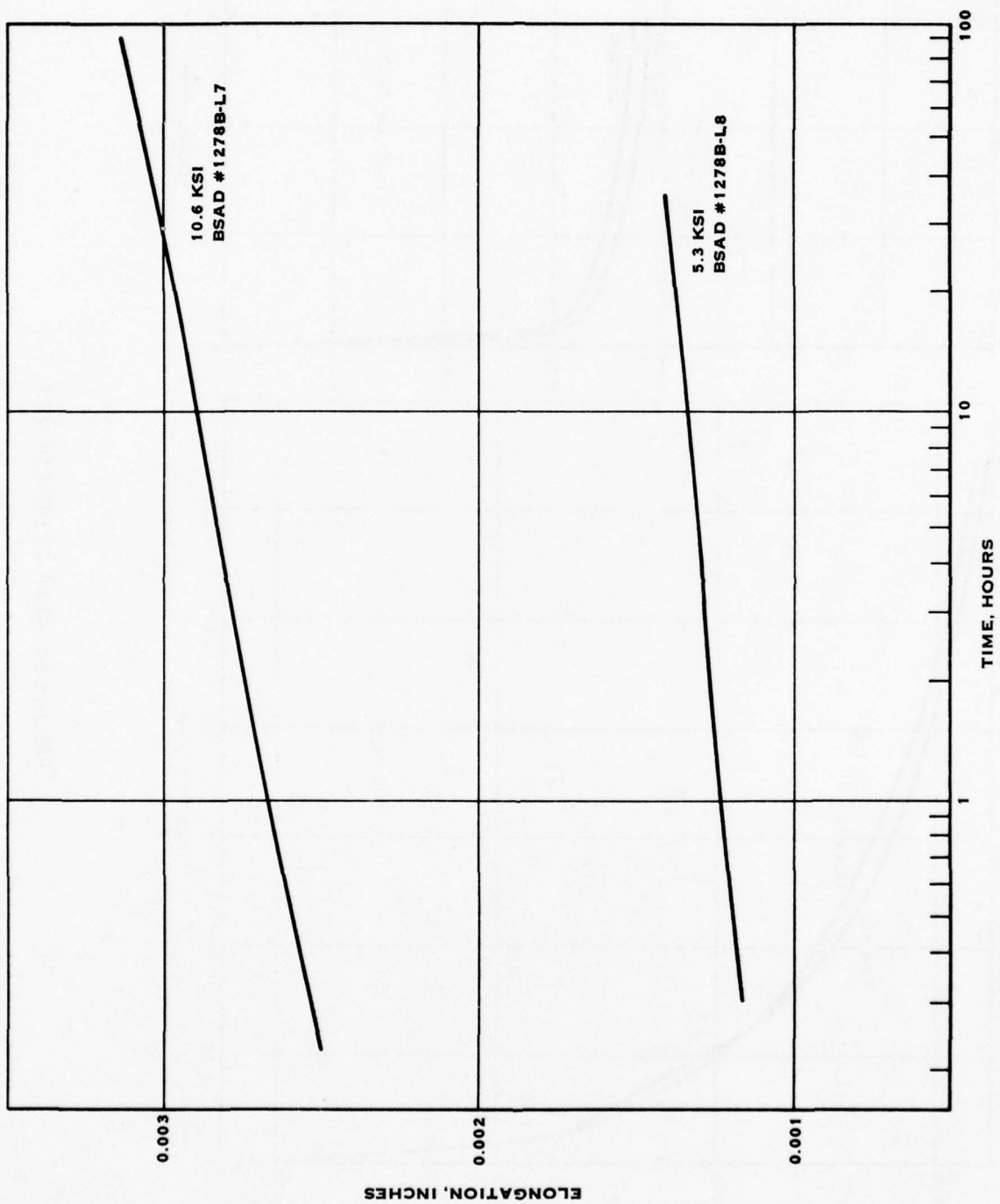


FIGURE 65. 450°F CREEP CURVES

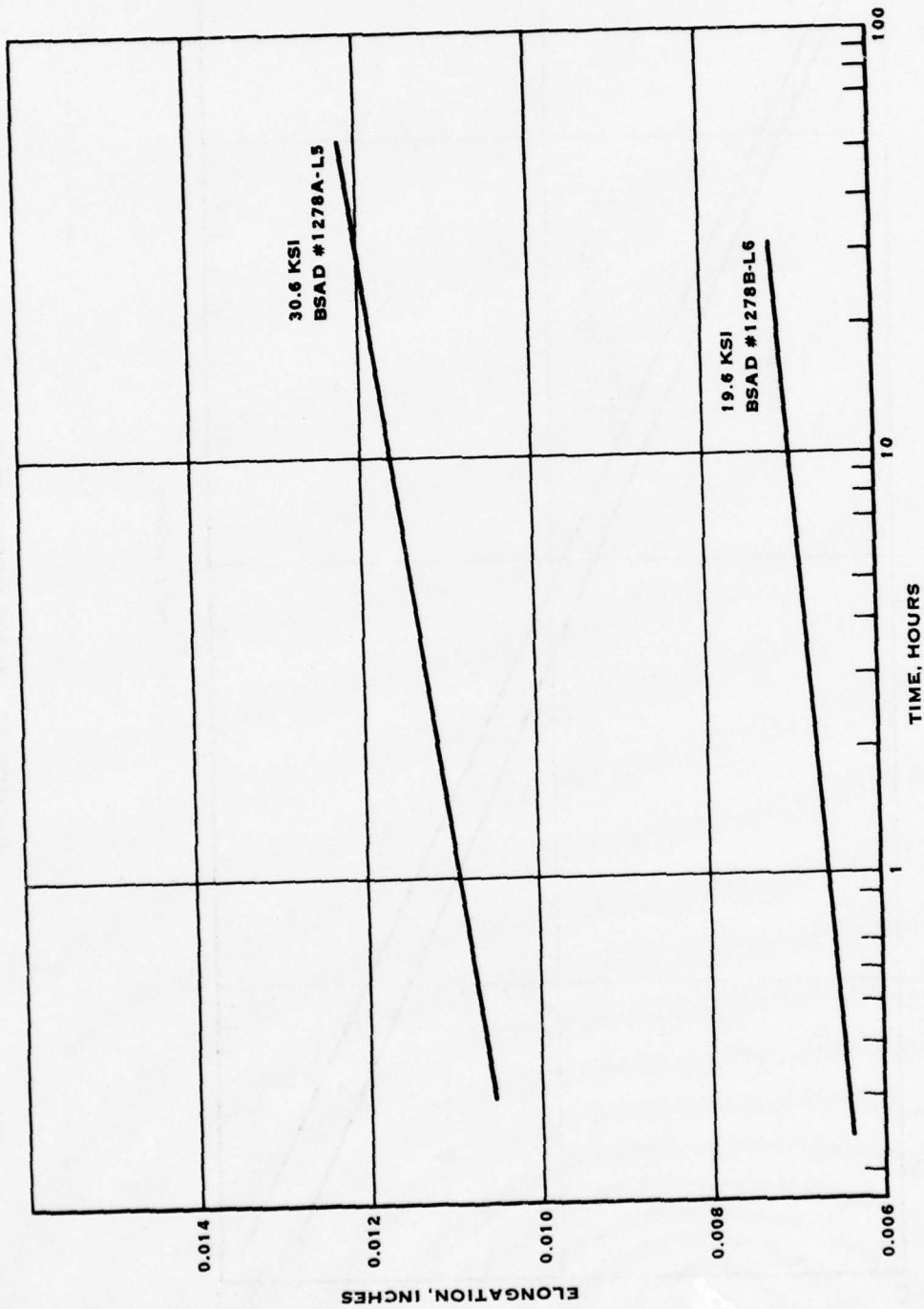


FIGURE 66. 450°F CREEP CURVES

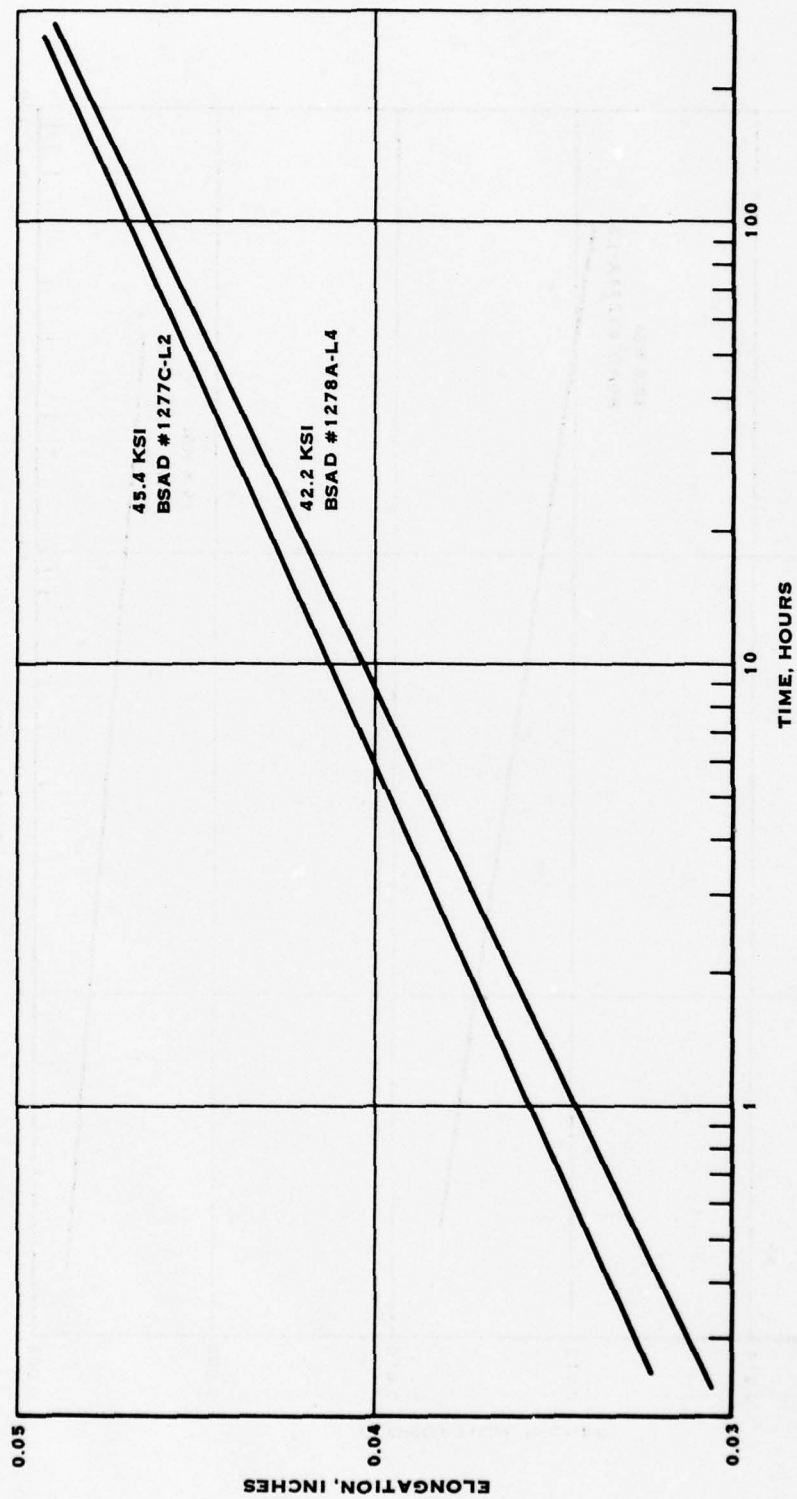


FIGURE 67. 450°F CREEP CURVES

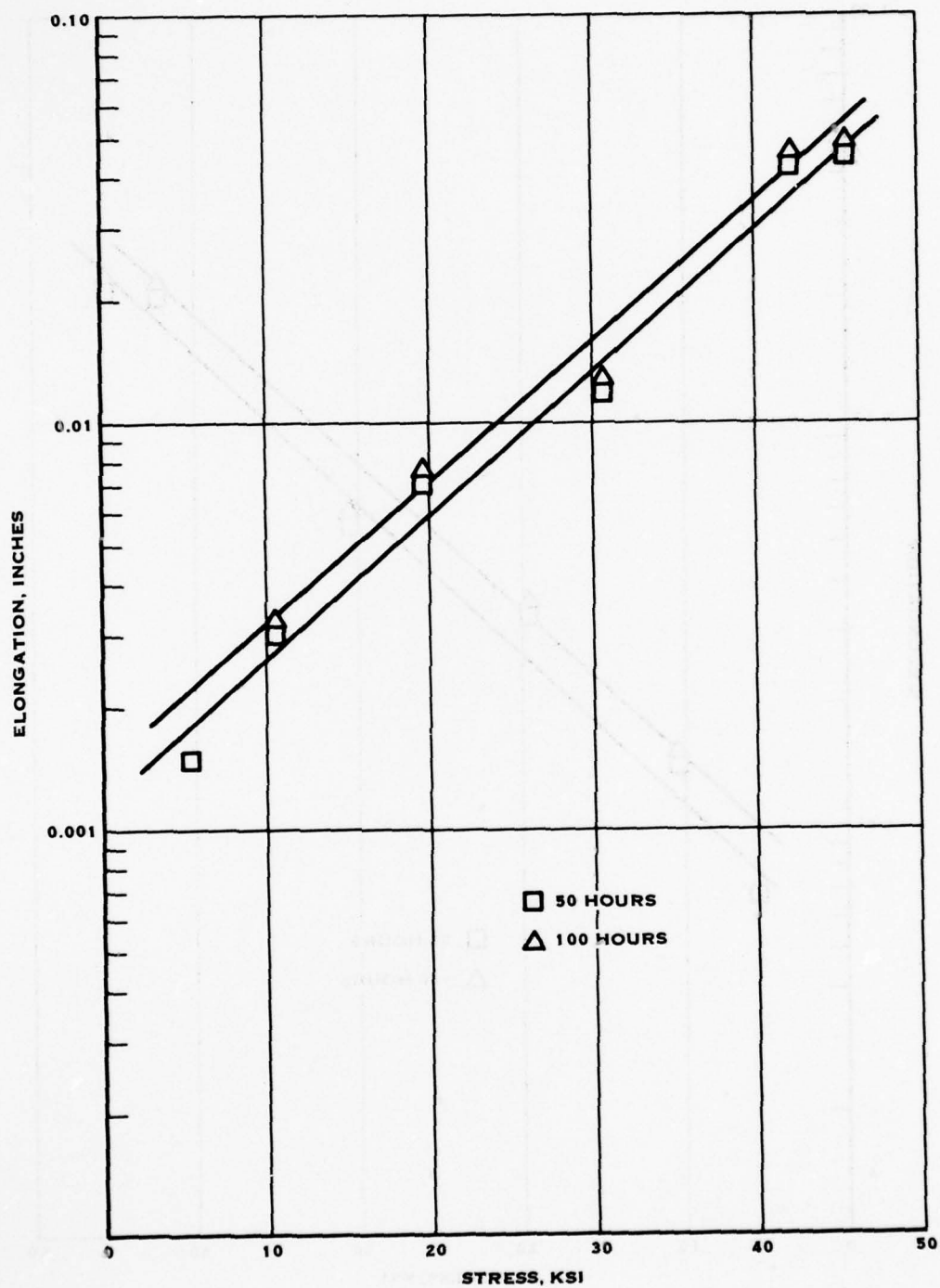


FIGURE 68. 450°F CREEP CURVES

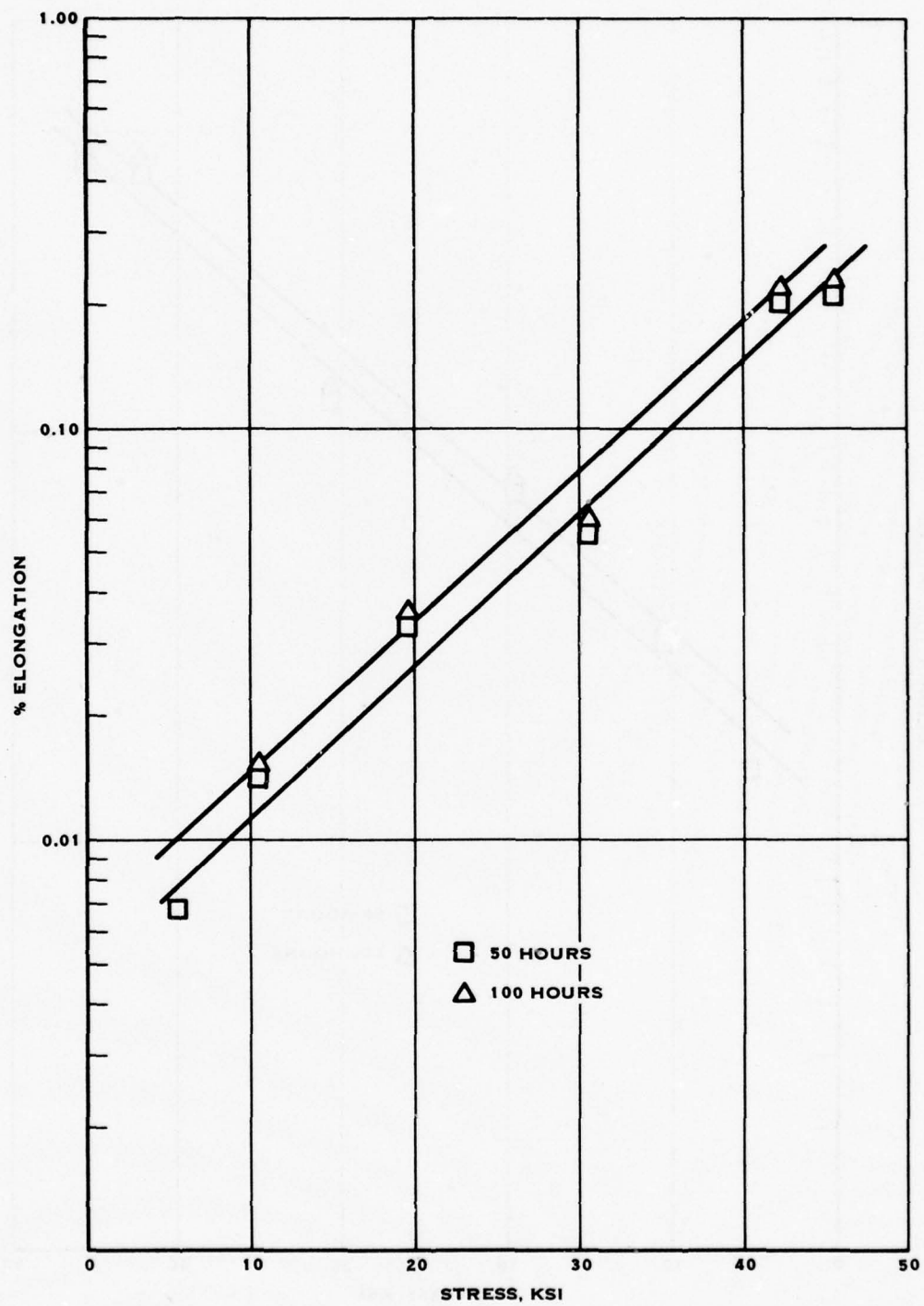


FIGURE 69. 450°F CREEP CURVES

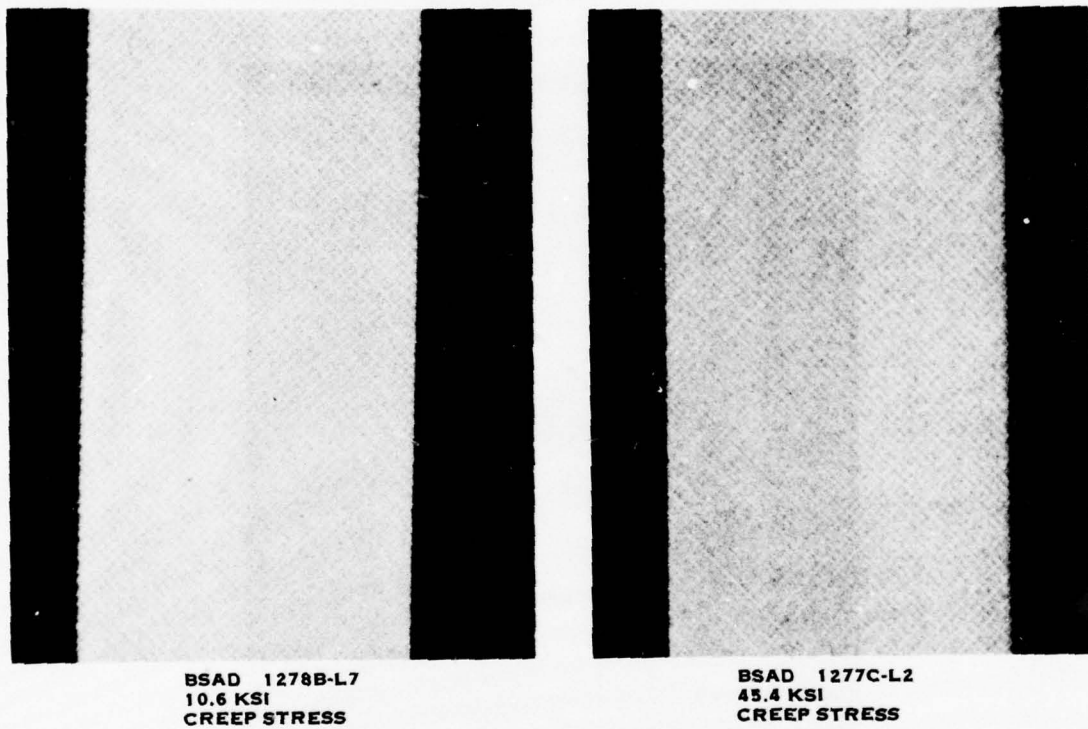


FIGURE 70. RADIOGRAPH OF TWO CREEP SPECIMENS

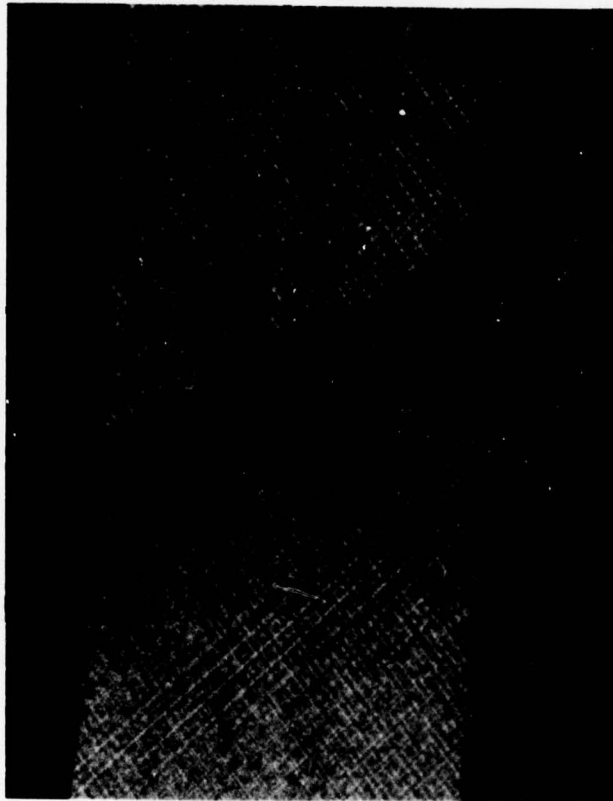


FIGURE 71. RADIOGRAPH OF FRACTURED STRESS RUPTURE SPECIMEN

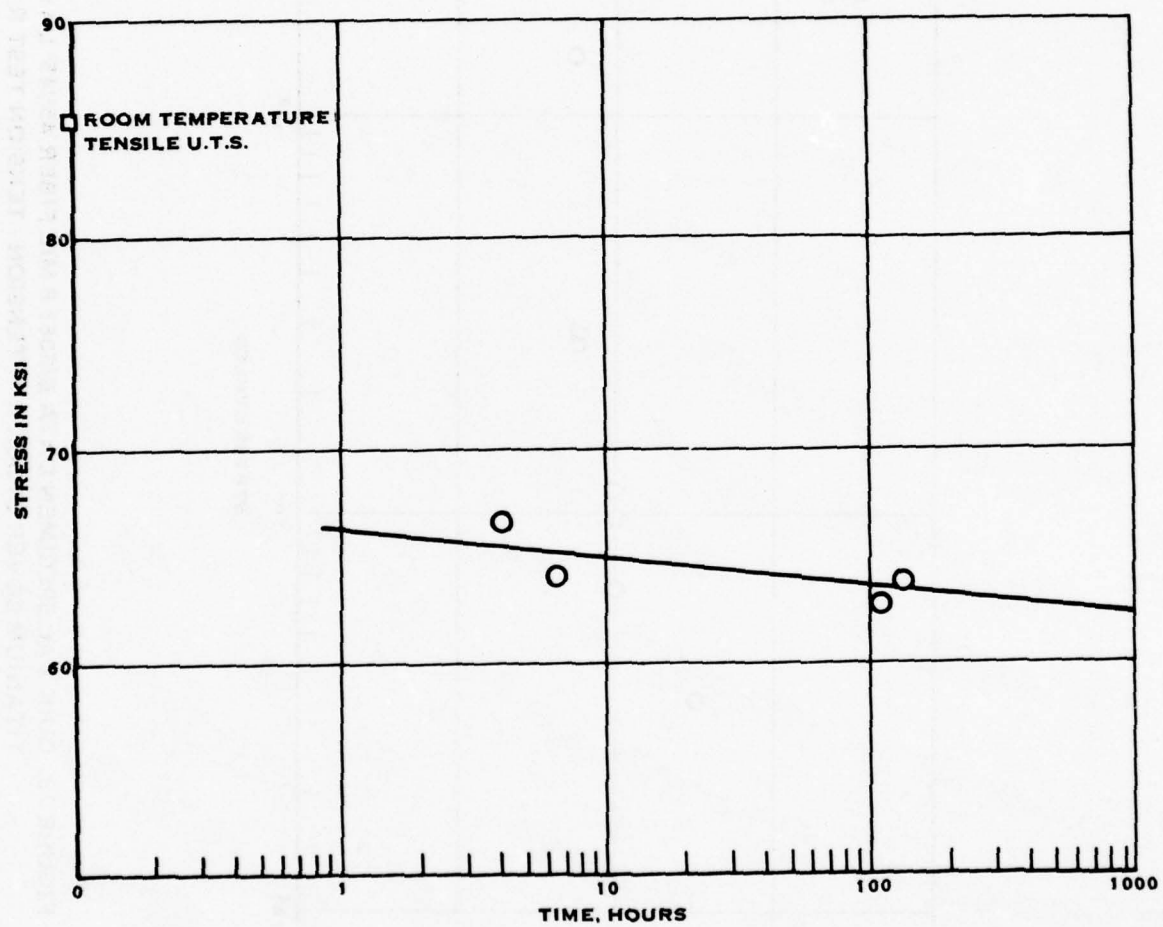


FIGURE 72. STRESS CORROSION 3.5 NaCL SOLUTION AT ROOM TEMPERATURE

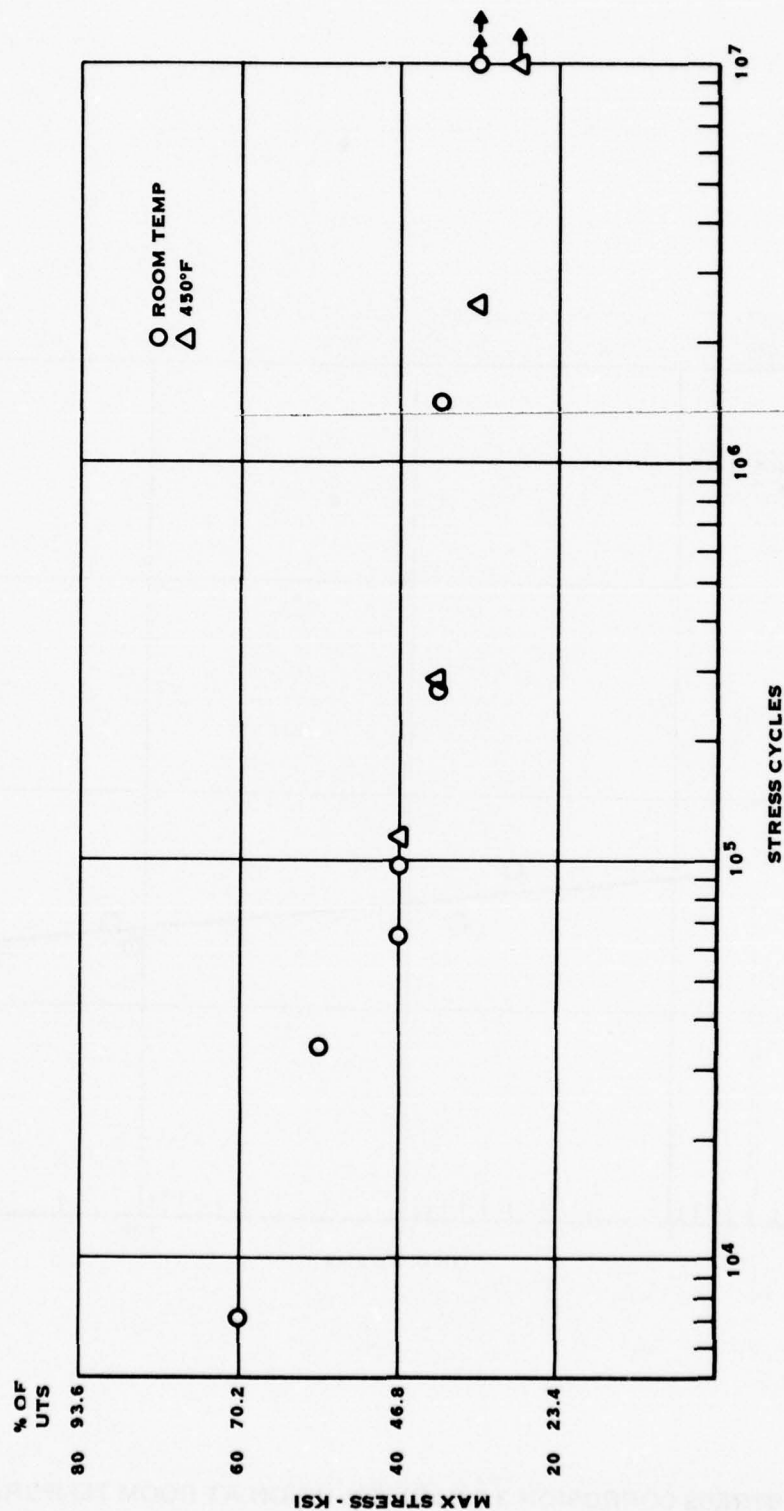


FIGURE 73. QUIK VAC SPECIMEN DATA B/6061 8 MIL FIBER 45°/45° LAYUP
TITANIUM COVER STOCK R.T. TENSION - TENSION TEST R = 0.1

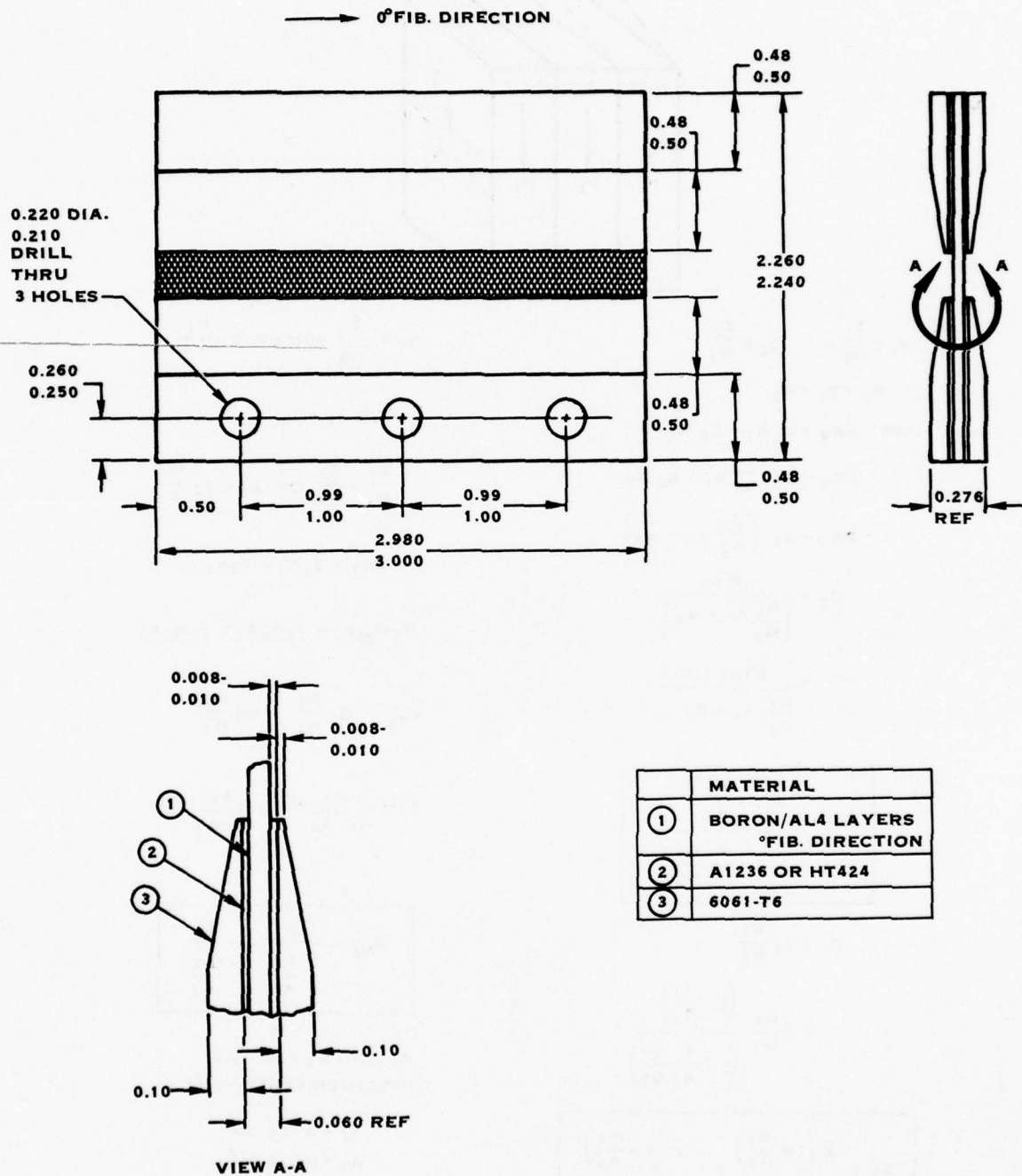
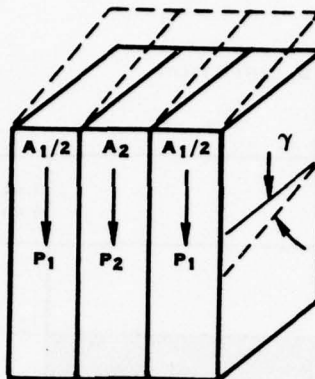


FIGURE 74. RAIL SHEAR SPECIMEN



$$\gamma_1 = \frac{z_1}{G_1} \quad \gamma_2 = \frac{z_2}{G_2}$$

$$P_T = P_1 + P_2$$

$$\text{OR } \bar{z} A_T = z_1 A_1 + z_2 A_2$$

$$\bar{z} A_T = z_2 \frac{G_1}{G_2} A_1 + z_2 A_2$$

$$\bar{z} A_T = z_2 \left[\frac{G_1}{G_2} A_1 + A_2 \right]$$

$$z_2 = \frac{\bar{z} A_T}{\left[\frac{G_1}{G_2} A_1 + A_2 \right]}$$

$$= \frac{\bar{z} (A_1 + A_2)}{\frac{G_1}{G_2} A_1 + A_2}$$

$$z_2 = \frac{\bar{z} \left(1 + \frac{A_1}{A_2} \right)}{\left(1 + \frac{A_1 G_1}{A_2 G_2} \right)}$$

$$z_1 = z_2 \frac{G_1}{G_2}$$

$$= \bar{z} \frac{G_1}{G_2} \frac{\left(1 + \frac{A_1}{A_2} \right)}{\left(1 + \frac{A_1 G_1}{A_2 G_2} \right)}$$

$$z_1 = \frac{\bar{z} \left(1 + \frac{A_1}{A_2} \right)}{\left(\frac{G_2}{G_1} + \frac{A_1}{A_2} \right)} = \frac{\bar{z} \left(1 + \frac{A_1}{A_2} \right)}{\left(1 + \frac{A_2 G_2}{A_1 G_1} \right)}$$

$$\gamma_T = \frac{\bar{z}}{G_{eg}} \text{ WHERE } \bar{z} = \frac{P_T}{A_T}$$

$$\gamma_1 = \gamma_2 = \gamma_T$$

$$\frac{z_1}{G_1} = \frac{z_2}{G_2} \text{ OR } z_1 = z_2 \frac{G_1}{G_2}$$

$$\bar{z} A_T = z_1 A_1 + z_2 A_2$$

$$\gamma_T G_{eg} A_1 = \gamma_1 G_1 A_1 + \gamma_2 G_2 A_2$$

$$G_{eg} = G_1 \frac{A_1}{A_T} + G_2 \frac{A_2}{A_T}$$

$$= G_1 \frac{A_1}{A_1 + A_2} + G_2 \frac{A_2}{A_1 + A_2}$$

$$G_{eg} = \frac{G_1}{1 + \frac{A_2}{A_1}} + \frac{G_2}{1 + \frac{A_1}{A_2}}$$

A_1 AND A_2 FOR THE SPECIMEN TESTED ARE

$$A_2 = 0.108 \text{ IN}^2$$

$$A_1 = 0.072 \text{ IN}^2$$

FIGURE 75. ELASTIC STRESS RELATIONSHIPS

APPENDIX A
SPECIFICATION FOR 8 MIL BORON/6061 PLASMA SPRAYED TAPE

HAMILTON STANDARD
Division of United Technologies Corp.
Windsor Locks, Conn. 06096
Code Identification 73030

Specification No. HS 7108
Rev.
page 2

1.0 SCOPE

This specification covers the detailed requirements for boron filament-aluminum matrix composite tape consisting of one single layer of 8.0 mil diameter boron filament in a matrix of AA6061 plasma-sprayed powder and 2 mil thick AA6061 foil. This tape will contain 51.5 ± 2.5 percent filament by volume and 93 ± 2 filaments/inch. In addition, this specification covers the detailed requirements for a multilayer unidirectional composite flat panel made from this tape.

2.0 APPLICABLE DOCUMENTS

The below listed documents of the exact issue shown (or, in the case of Hamilton Standard documents, the current issue as defined by the engineering release and change procedure) form a part of this specification to the extent referred to herein. When the requirements of any of the documents so referenced conflict with the requirements of this specification, the requirements of this specification shall take precedence.

2.1 Hamilton Standard

Hamilton Standard 1550 - Cleanliness, Preservation and Handling of Products, Process Specification for

2.2 Industry

AA6061 - Aluminum Alloy

CMC 110 - Filament, Boron, Plain, Material Specification for

3.0 REQUIREMENTS

3.1 General Requirements

The tape shall be acquired from approved sources. The tape shall be produced by plasma spraying aluminum alloy powder on a parallel array of 8.0 mil diameter boron filaments backed by a 2 mil thick aluminum alloy foil.

3.1.1 Raw Materials

3.1.1.1 Filament - The filament shall have a minimum average UTS of 450,000 psi, a corresponding standard deviation (one) σ , of 80,000 psi and a minimum Young's modulus of 55,000,000 psi. It shall be the tape fabricators responsibility to verify by certification that the filament vendor has not made any process changes since the last performance tests were made.

3.1.1.2 Foil - The foil material shall be AA6061. The foil shall have a thickness of 2 mils \pm 0.1 mils.

3.1.1.3 Aluminum Powder Spray - The material to be plasma sprayed will be powder, conforming to the chemical composition of AA6061. The material will be prepared by atomization, and with a minimal screen analysis such that all powder will be minus 225 mesh with 95 weight percent minus 270 mesh. Powder type and source shall not be changed without the written approval of the vendee.

3.2 Tape Requirements

3.2.1 Stains - Tape shall exhibit no visible stains, finger prints, dust, dirt or contamination per HS 1550, Class 2.

3.2.2 Edge Delamination - Edge delamination shall not extend more than 0.05 inch from any edge.

3.2.3 Tape Foil Ripples or Wrinkles - The tape may contain visual foil ripples or wrinkles in accordance with Engineering approved standards.

3.2.4 Filament Count - For each inch of tape width there shall be 94 ± 2 filaments.

3.2.5 Missing Filaments - A tape must not have more than two missing filaments in any one inch of width.

3.2.6 Gaps - Filament gaps over 0.010 inch must be at least one inch apart.

3.2.7 Loose Filaments - Tape shall contain no loose filaments.

3.2.8 Volume Percent Boron Filament - The tape shall contain 51.5 ± 2.5 percent filament by volume.

3.2.9 Filament Arrangement - Filaments shall be oriented approximately parallel to each other and shall be approximately equally spaced. Crossed over filaments are not permitted.

3.2.10 Splices - No filament splices shall be permitted in a tape.

3.2.11 Tape Thickness - Thickness of the tape shall be 0.014 inches. Maximum and minimum variation shall be within a 0.002 inch range.

3.2.12 Tape Fabricability - Tape shall be capable of being manufactured into a panel that will meet the requirements specified herein.

3.2.13 Process Approval - Processing procedures and parameters shall be approved by the vendee.

3.2.14 Areal Weight - Tape minimum areal weight shall be 0.370 grams per square inch.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection and Tests

4.1.1 Responsibility - The vendor shall be responsible for compliance with all inspections and tests specified herein.

4.1.2 Location - All inspections and tests specified herein shall be performed at the facility of the vendor, or an independent testing organization acceptable to the vendee.

4.1.3 Records and Data - Records and test data shall be maintained in a complete and up-to-date form and shall be made available to the vendee at the time of the submission of each lot of processed tape for acceptance and be maintained for five years. Records shall identify the tape by serial number along with the tape properties and the test mechanical properties data obtained from each panel.

4.1.4 Physical Properties Testing of Tape

4.1.4.1 Volume Percent Boron Filament - Volume percent of filament shall be calculated on every production tape.

4.1.4.2 Filament Properties - The UTS, x_{10} , per run will be calculated from the average of (10) individual test specimens. The standard deviation, (one) σ , will be calculated for all the strength values accumulated weekly. All other filament properties shall be tested in accordance with the requirements of CMC 110. The UTS, x_{10} , will be provided for each spooled length of fiber used in a tape.

4.1.5 Tape Inspection

4.1.5.1 Spacing - Spacing in filaments per inch for each inch of width shall be measured for every tape by:

4.1.5.1 (Continued)

a. Measuring the width of filament wound area in inches to the nearest 1/32 and dividing by the number of filaments shown on the winding counter, or

b. Counting the number of filaments in a 0.250 ± 0.001 inch length per inch of width and obtaining a spacing spectrum across the tape.

4.1.5.2 Tape Defects - Missing filaments, stains, gaps, foil ripples or wrinkles, edge delamination, crossover, loose filaments and splices shall be specifically inspected for on both sides of every tape. Unaided visual plus low power magnification 3X techniques shall be employed. Defects found shall be cut out of the tape or marked by written procedures approved by the vendee.

4.1.5.3 Edge Delamination - This requirement is waived if it can be shown that the delaminated area is subsequently trimmed and does not remain in the final part.

4.1.5.4 Tape Thickness - A total of three thickness measurements will be made at one end of each tape. One of these will be at the middle and one each within one inch of the trimmed edges.

4.1.6 Test Panel Requirements

4.1.6.1 Handling - All handling of the tape shall be performed using clean non-linting fabric gloves.

4.1.6.1.1 Sampling - Sampling will be conducted as required by the vendee.

4.1.6.2 Cutting - Tape plies shall be cut using clean, sharp instruments.

4.1.6.3 Ply Size - Tape plies will be cut to a size of 5 inches by 3.5 inches with the fiber orientation as given in Fig. 1. The tape shall be wiped with MEK on the foil side only.

4.1.6.4 Stacking Sequence - Six cut plies will be correctly stacked to form a unidirectional panel layup with the fiber orientation as given in Fig. 1. The plies will be stacked in a given sequence so that the tape foil is the bottom surface, as shown in Fig. 2. A 2 mil foil of AA6061 will be placed on the top of the six stacked plies to serve as a cover sheet, as shown in Fig. 2.

4.1.6.5 Diffusion Bonding

4.1.6.5.1 Release Agent - A release agent approved by the vendee shall be used.

4.1.6.5.2 Diffusion Bonding Parameters - Diffusion bonding shall be in air in a fast moving platen press facility, load applied to the panel shall produce a pressure of 5500 - 6000 psi. The diffusion bonding temperature shall be 1015 ± 10 Deg. F, and maintained for a period of 9 to 10 minutes; heating rate to the bonding temperature will be 400 Deg. F/minute. Panel cooling shall be achieved by rapid removal from the press, placement on a flat steel plate and subsequent air quenching in a stream of compressed air. The minimum cooling rate shall be 120 Deg. F/minute. Alternate procedures may be used if approved in writing by the vendee.

4.1.6.5.3 Process Approval - Processing procedures and process parameters shall be approved in writing by the vendee.

4.1.6.6 Panel Physical Properties

4.1.6.6.1 Delaminations - The composite panel shall contain no visible delaminations.

4.1.6.6.2 Thickness - The composite panel thickness shall vary by no more than ± 1.5 mils for average panel thicknesses ranging from 40 mils to 120 mils.

4.1.6.7 Panel Mechanical Properties

4.1.6.7.1 Specimen Location - Mechanical properties will be determined by testing specimens taken from a unidirectional 6 ply panel, 3.5 inches by 5 inches, shown in Fig. 1.

4.1.6.7.2 Longitudinal Tensile Strength - Two specimens, #1 and #3, as indicated in Fig. 1, will be tested from each test panel. For both specimens, the minimum acceptable tensile strength is 150,000 psi. The test specimen configuration will conform to the dimensions shown in Fig. 3.

4.1.6.7.3 Longitudinal Tensile Modulus - The modulus for only specimen #3, Fig. 1, will be determined and must be equal to or greater than 30×10^6 psi; strain gage measurement techniques will be used.

4.1.6.7.4 Transverse Tensile Strength - Two specimens, numbers 4 and 7, as indicated in Fig. 1, will be tested from each test panel. The minimum acceptable strength for each specimen is 12,000 psi. The test specimen configuration will conform to the dimensions shown in Fig. 4.

4.1.6.7.5 Transverse Tensile Modulus - The modulus for only specimen #7, Fig. 1, will be determined and must be equal to or greater than 16×10^6 psi; strain gage measurement techniques will be used.

4.1.6.8 NDT Panel Inspection

4.1.6.8.1 All composite panels will be visually inspected at 5X magnification for defects.

4.1.6.8.2 For every panel, two thickness measurements will be made at each indicated location:

- a. 1/4" from each corner along the diagonal connecting the corners.
- b. At the midpoint of each side of the panel, 1/4" in from the panel edge.
- c. Along each diagonal at the midpoint between the panel center and the panel corner.
- d. At the panel center.

4.1.6.9 Acceptance Specimens - Tensile test specimens shall be cut from each composite panel, as indicated in Fig. 1. Ends of tensile specimens will be padded prior to test, as shown in Fig. 3, for longitudinal tensile specimens and in Fig. 4 for transverse tensile specimens. Aluminum tabs can be substituted for the fiberglass pads shown in Figs. 3 and 4.

4.1.6.10 Tensile Tests - The composite tensile specimens shall be tested to ascertain if they meet the strength property requirements listed in 4.1.6.7. The tests shall be performed at a crosshead movement rate of 0.05 ± 0.02 inch/inch/minute. Test section thickness shall be recorded for each specimen along with the strength properties. With respect to specimens gaged for modulus determinations, the grips will be adjusted so bending is restricted to 5% or less over the gage length.

4.2 Powder Properties

A second chemical analysis and mesh analysis of the powder used, shall be made prior to spraying.

4.3 Certification

The vendor shall submit with each shipment of tape a certified report in accordance with the instructions of the vendee.

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging

5.1.1 Preservation - Tape ends shall be protected by wrapping with masking tape across the ends.

5.1.2 Packaging - Each tape shall be completely enclosed in at least one layer of sheet polyethylene wrapping material at least 0.004 inches thick and otherwise protected against permanent distortion and against damage from exposure to weather or any normal hazard.

5.2 PACKING

5.2.1 Cylindrical Packing - Tapes to be shipped by commercial carrier shall be packed in a cylindrical container. The diameter of any rolled tape shall be not less than fourteen inches and container wall thickness shall be at least 1/16 inches. Sufficient packing material shall be utilized to prevent relative tape motion during transit.

5.3 Identification

5.3.1 Tape - Each tape shall be marked by attaching a card inside the polyethylene wrapper with the tape using characters not less than 1/4 inch in height, which will not be obliterated by normal handling. The following information shall be written on the card:

Hamilton Standard Specification Number
Tape Number
Size in Square Feet
Weight per Unit Area in Grams per Square Inch
Purchase Order Number
Diameter of Filament or Filaments in Tape (Measured)
Calculated Volume Percent Filament
UTS x10 of Filament or Filaments in Tape
Filament Lot Number & Corresponding Winding Width
Foil Designation
Powder Metal Designation

5.3.2 Shipping Container - Each shipping container shall be marked with the following information:

Name of Manufacturer
Purchase Order Number
Tape No. Identification

6.0 NOTES

6.1 Vendor

The vendor is the company to whom the vendee has issued a purchase order for supplies and/or services covered in whole or in part by this specification. (In those cases in which these supplies and/or services are to be furnished by a department of the vendee, the vendor is that department.)

REQUIREMENT/VERIFICATION INDEX (for reference only)

REQUIREMENT	CATE- GORY *	SECTION 3 REQUIREMENT PARAGRAPH	SECTION 4 VERIFICATION PARAGRAPH
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Tape Ply Properties

Stains	3.2.1	4.1.5.2
Edge Delamination	3.2.2	4.1.5.3
Tape Ply Foil Ripples or Wrinkles	3.2.3	4.1.5.2
Missing Filaments	3.2.5	4.1.5.1 & 4.1.5.2
Gaps	3.2.6	4.1.5.1 & 4.1.5.2
Loose Filaments	3.2.7	4.1.5.1 & 4.1.5.2
Volume Percent Boron Filament	3.2.8	4.1.4.1
Filament Count	3.2.4	4.1.5.1
Filament Arrangement	3.2.9	4.1.5.2
Splices	3.2.10	4.1.5.2
Tape Thickness	3.2.11	4.1.5.4
Tape Fabricability	3.2.12	4.1.6.7

Powder Properties

Aluminum Powder Spray	3.1.1.3	4.2
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*Legend	<u>INSPECTION CATEGORY</u>	<u>TEST CATEGORY</u>
1. visual	4. process control	A. prototype approval
2. nondestructive	5. certification	B. acceptance
3. destructive	6. other	C. qualification
		D. other

All Other Contracts Between the Vendor and Hamilton Standard shall be via Purchasing.

3.1 Tape Source - Tape source will be approved by Hamilton Standard Project Engineering.

4.1.2 Vendee shall be Hamilton Standard Quality Control and Materials Engineering.

4.1.5.2 The vendee shall be Hamilton Standard Manufacturing Engineering.

4.1.6.1.1 Sampling - One panel shall be fabricated and tested for every 250 square feet of tape delivered to Hamilton Standard Receiving Inspection to the specification. For purposes of determining test frequency, all quantities of tape delivered to this specification to Hamilton Standard will be treated as cumulative quantities.

4.1.6.5.1 The vendee shall be Hamilton Standard Project Engineering.

4.1.6.5.2 The vendee shall be Hamilton Standard Materials Engineering.

3.2.13 -- and 4.1.6.5.3 The vendee shall be Hamilton Standard Project Engineering and Materials Engineering. Approval shall consist of countersigning Operation Sheets by the Vendee.

4.3 The Vendee shall be Hamilton Standard Quality Control.

The certified report shall be submitted in duplicate as an attachment to the shipping papers. The report shall include the following as part of the certification:

- a. longitudinal tensile strength of specimens #1 and #3
- b. modulus for specimen #3
- c. transverse tensile strength of specimens #4 and #7
- d. modulus for specimen #7
- e. panel thickness measurements as specified in 4.1.6.8.2
- f. chemical composition, as specified in 4.2
- g. tape identification number, as specified in 5.3.1
- h. filament diameter and calculated filament volume percent, as specified in 5.3.1
- i. powder mesh size prior to spraying as specified in 4.2

APPENDIX B
SPECIFICATION FOR 8 MIL BORON/1100 PLASMA SPRAYED TAPE

HAMILTON STANDARD
Division of United Technologies Corp.
Windsor Locks, Conn., 06096
Code Identification 73030

Specification No. HS 7109
Rev.
page 2

1.0 SCOPE

This specification covers the detailed requirements for boron filament-aluminum matrix composite tape consisting of one single layer of 8.0 mil diameter boron filament in a matrix of AA1100 plasma-sprayed powder and 2 mil thick AA1100 foil. This tape will contain 51.5 ± 2.5 percent filament by volume and 93 ± 2 filaments/inch. In addition, this specification covers the detailed requirements for a multilayer unidirectional composite flat panel made from this tape.

2.0 APPLICABLE DOCUMENTS

The below listed documents of the exact issue shown (or, in the case of Hamilton Standard documents, the current issue as defined by the engineering release and change procedure) form a part of this specification to the extent referred to herein. When the requirements of any of the documents so referenced conflict with the requirements of this specification, the requirements of this specification shall take precedence.

2.1 Hamilton Standard

Hamilton Standard 1550 - Cleanliness, Preservation and Handling of Products, Process Specification for

2.2 Industry

AA1100 - Aluminum Alloy
CMC 110 - Filament, Boron, Plain, Material Specification for

3.0 REQUIREMENTS

3.1 General Requirements

The tape shall be acquired from approved sources. The tape shall be produced by plasma spraying aluminum alloy powder on a parallel array of 8.0 mil diameter boron filaments backed by a 2 mil thick aluminum alloy foil.

3.1.1 Raw Materials

3.1.1.1 Filament - The filament shall have a minimum average UTS of 450,000 psi, a corresponding standard deviation (one) σ , of 80,000 psi and a minimum Young's modulus of 55,000,000 psi. It shall be the tape fabricators responsibility to verify by certification that the filament vendor has not made any process changes since the last performance tests were made.

3.1.1.2 Foil - The foil material shall be AA1100. The file shall have a thickness of 2 mils \pm 0.1 mils.

3.1.1.3 Aluminum Powder Spray - The material to be plasma sprayed will be powder, conforming to the chemical composition of AA1100. The material will be prepared by atomization, and with a minimal screen analysis such that all powder will be minus 225 mesh with 95 weight percent minus 270 mesh. Powder type and source shall not be changed without the written approval of the vendor.

3.2 Tape Requirements

3.2.1 Stains - Tape shall exhibit no visible stains, finger prints, dust, dirt or contamination per HS 1550, Class 2.

3.2.2 Edge Delamination - Edge delamination shall not extend more than 0.05 inch from any edge.

3.2.3 Tape Foil Ripples or Wrinkles - The tape may contain visual foil ripples or wrinkles in accordance with Engineering approved standards.

3.2.4 Filament Count - For each inch of tape width there shall be 94 ± 2 filaments.

3.2.5 Missing Filaments - A tape must not have more than two missing filaments in any one inch of width.

3.2.6 Gaps - Filament gaps over 0.010 inch must be at least one inch apart.

3.2.7 Loose Filaments - Tape shall contain no loose filaments.

3.2.8 Volume Percent Boron Filament - The tape shall contain 51.5 ± 2.5 percent filament by volume.

3.2.9 Filament Arrangement - Filaments shall be oriented approximately parallel to each other and shall be approximately equally spaced. Crossed over filaments are not permitted.

3.2.10 Splices - No filament splices shall be permitted in a tape.

3.2.11 Tape Thickness - Thickness of the tape shall be 0.014 inches. Maximum and minimum variation shall be within a 0.002 inch range.

3.2.12 Tape Fabricability - Tape shall be capable of being manufactured into a panel that will meet the requirements specified herein.

3.2.13 Process Approval - Processing procedures and parameters shall be approved by the vendee.

3.2.14 Areal Weight - Tape minimum areal weight shall be 0.370 grams per square inch.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection and Tests

4.1.1 Responsibility - The vendor shall be responsible for compliance with all inspections and tests specified herein.

4.1.2 Location - All inspections and tests specified herein shall be performed at the facility of the vendor, or an independent testing organization acceptable to the vendee.

4.1.3 Records and Data - Records and test data shall be maintained in a complete and up-to-date form and shall be made available to the vendee at the time of the submission of each lot of processed tape for acceptance and be maintained for five years. Records shall identify the tape by serial number along with the tape properties and the test mechanical properties data obtained from each panel.

4.1.4 Physical Properties Testing of Tape

4.1.4.1 Volume Percent Boron Filament - Volume percent of filament shall be calculated on every production tape.

4.1.4.2 Filament Properties - The UTS, σ , per run will be calculated from the average of (10) individual test specimens. The standard deviation, (one) σ , will be calculated for all the strength values accumulated weekly. All other filament properties

4.1.4.2 (Continued)

shall be tested in accordance with the requirements of CMC 110. The UTS, X_{10} , will be provided for each spooled length of fiber used in a tape.

4.1.5 Tape Inspection

4.1.5.1 Spacing - Spacing in filaments per inch for each inch of width shall be measured for every tape by:

a. Measuring the width of filament wound area in inches to the nearest $1/32$ and dividing by the number of filaments shown on the winding counter, or

b. Counting the number of filaments in a 0.250 ± 0.001 inch length per inch of width and obtaining a spacing spectrum across the tape.

4.1.5.2 Tape Defects - Missing filaments, stains, gaps, foil ripples or wrinkles, edge delamination, crossover, loose filaments and splices shall be specifically inspected for on both sides of every tape. Unaided visual plus low power magnification 3X techniques shall be employed. Defects found shall be cut out of the tape or marked by written procedures approved by the vendee.

4.1.5.3 Edge Delamination - This requirement is waived if it can be shown that the delaminated area is subsequently trimmed and does not remain in the final part.

4.1.5.4 Tape Thickness - A total of three thickness measurements will be made at one end of each tape. One of these will be at the middle and one each within one inch of the trimmed edges.

4.1.6 Test Panel Requirements

4.1.6.1 Handling - All handling of the tape shall be performed using clean non-linting fabric gloves.

4.1.6.1.1 Sampling - Sampling will be conducted as required by the vendee.

4.1.6.2 Cutting - Tape plies shall be cut using clean, sharp instruments.

4.1.6.3 Ply Size - Tape plies will be cut to a size of 5 inches by 3.5 inches with the fiber orientation as given in Fig. 1. The tape shall be wiped with MEK on the foil side only.

4.1.6.4 Stacking Sequence - Six cut plies will be correctly stacked to form a unidirectional panel layup with the fiber orientation as given in Fig. 1. The plies will be stacked in a given sequence so that the tape foil is the bottom surface, as shown in Fig. 2. A 2 mil foil of AA1100 will be placed on the top of the six stacked plies to serve as a cover sheet, as shown in Fig. 2.

4.1.6.5 Diffusion Bonding

4.1.6.5.1 Release Agent - A release agent approved by the vendee shall be used.

4.1.6.5.2 Diffusion Bonding Parameters - Diffusion bonding shall be in air in a fast moving platen press facility, load applied to the panel shall produce a pressure of 5500 - 6000 psi. The diffusion bonding temperature shall be 1015 ± 10 Deg. F, and maintained for a period of 9 to 10 minutes; heating rate to the bonding temperature will be 400 Deg. F/minute. Panel cooling shall be achieved by rapid removal from the press, placement on a flat steel plate and subsequent air quenching in a stream of compressed air. The minimum cooling rate shall be 120 Deg. F/minute. Alternate procedures may be used if approved in writing by the vendee.

4.1.6.5.3 Process Approval - Processing procedures and process parameters shall be approved in writing by the vendee.

4.1.6.6 Panel Physical Properties

4.1.6.6.1 Delaminations - The composite panel shall contain no visible delaminations.

4.1.6.6.2 Thickness - The composite panel thickness shall vary by no more than ± 1.5 mils for average panel thicknesses ranging from 40 mils to 120 mils.

4.1.6.7 Panel Mechanical Properties

4.1.6.7.1 Specimen Location - Mechanical properties will be determined by testing specimens taken from a unidirectional 6 ply panel, 3.5 inches by 5 inches, shown in Fig. 1.

4.1.6.7.2 Longitudinal Tensile Strength - Two specimens, #1 and #3, as indicated in Fig. 1, will be tested from each test panel. For both specimens, the minimum acceptable tensile strength is 150,000 psi. The test specimen configuration will conform to the dimensions shown in Fig. 3.

4.1.6.7.3 Longitudinal Tensile Modulus - The modulus for only specimen #3, Fig. 1, will be determined and must be equal to or greater than 30×10^6 psi; strain gage measurement technique will be used.

4.1.6.7.4 Transverse Tensile Strength - Two specimens, numbers 4 and 7, as indicated in Fig. 1, will be tested from each test panel. The minimum acceptable strength for each specimen is 10,000 psi. The test specimen configuration will conform to the dimensions shown in Fig. 4.

4.1.6.7.5 Transverse Tensile Modulus - The modulus for only specimen #7, Fig. 1, will be determined and must be equal to or greater than 16×10^6 psi; strain gage measurement techniques will be used.

4.1.6.8 NDT Panel Inspection

4.1.6.8.1 All composite panels will be visually inspected at 5X magnification for defects.

4.1.6.8.2 For every panel, two thickness measurements will be made at each indicated location:

- a. 1/4" from each corner along the diagonal connecting the corners.
- b. At the midpoint of each side of the panel, 1/4" in from the panel edge.
- c. Along each diagonal at the midpoint between the panel center and the panel corner.
- d. At the panel center.

4.1.6.9 Acceptance Specimens - Tensile test specimens shall be cut from each composite panel, as indicated in Fig. 1. Ends of tensile specimens will be padded prior to test, as shown in Fig. 3, for longitudinal tensile specimens and in Fig. 4 for transverse tensile specimens. Aluminum tabs can be substituted for the fiberglass pads shown in Figs. 3 and 4.

4.1.6.10 Tensile Tests - The composite tensile specimens shall be tested to ascertain if they meet the strength property requirements listed in 4.1.6.7. The tests shall be performed at a crosshead movement rate of 0.05 ± 0.02 inch/inch/minute. Test section thickness shall be recorded for each specimen along with the strength properties. With respect to specimens gaged for modulus determinations, the grips will be adjusted so bending is restricted to 5% or less over the gage length.

4.2 Powder Properties

A second chemical analysis and mesh analysis of the powder used, shall be made prior to spraying.

4.3 Certification

The vendor shall submit with each shipment of tape a certified report in accordance with the instructions of the vendee.

5.0 PREPARATION FOR DELIVERY

5.1 Preservation and Packaging

5.1.1 Preservation - Tape ends shall be protected by wrapping with masking tape across the ends.

5.1.2 Packaging - Each tape shall be completely enclosed in at least one layer of sheet polyethylene wrapping material at least 0.004 inches thick and otherwise protected against permanent distortion and against damage from exposure to weather or any normal hazard.

5.2 PACKING

5.2.1 Cylindrical Packing - Tapes to be shipped by commercial carrier shall be packed in a cylindrical container. The diameter of any rolled tape shall be not less than fourteen inches and container wall thickness shall be at least 1/16 inches. Sufficient packing material shall be utilized to prevent relative tape motion during transit.

5.3 Identification

5.3.1 Tape - Each tape shall be marked by attaching a card inside the polyethylene wrapper with the tape using characters not less than 1/4 inch in height, which will not be obliterated by normal handling. The following information shall be written on the card:

Hamilton Standard Specification Number
Tape Number
Size in Square Feet
Weight per Unit Area in Grams per Square Inch
Purchase Order Number
Diameter of Filament or Filaments in Tape (Measured)
Calculated Volume Percent Filament
UTS x₁₀ of Filament or Filaments in Tape
Filament Lot Number & Corresponding Winding Width
Foil Designation
Powder Metal Designation

5.3.2 Shipping Container - Each shipping container shall be marked with the following information:

Name of Manufacturer
Purchase Order Number
Tape No. Identification

6.0 NOTES

6.1 Vendor

The vendor is the company to whom the vendee has issued a purchase order for supplies and/or services covered in whole or in part by this specification. (In those cases in which these supplies and/or services are to be furnished by a department of the vendee, the vendor is that department.)

REQUIREMENT/VERIFICATION INDEX (for reference only)

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Stains	3.2.1	4.1.5.2
Edge Delamination	3.2.2	4.1.5.3
Tape Ply Foil Ripples or Wrinkles	3.2.3	4.1.5.2
Missing Filaments	3.2.5	4.1.5.1 & 4.1.5.2
Gaps	3.2.6	4.1.5.1 & 4.1.5.2
Loose Filaments	3.2.7	4.1.5.1 & 4.1.5.2
Volume Percent Boron Filament	3.2.8	4.1.4.1
Filament Count	3.2.4	4.1.5.1
Filament Arrangement	3.2.9	4.1.5.2
Splices	3.2.10	4.1.5.2
Tape Thickness	3.2.11	4.1.5.4
Tape Fabricability	3.2.12	4.1.6.7

Powder Properties

Aluminum Powder Spray	3.1.1.3	4.2
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*Legend	<u>INSPECTION CATEGORY</u>	<u>TEST CATEGORY</u>
1. visual	4. process control	A. prototype approval
2. nondestructive	5. certification	B. acceptance
3. destructive	6. other	C. qualification
		D. other

All Other Contracts Between the Vendor and Hamilton Standard shall be via Purchasing.

3.1 Tape Source - Tape Source will be approved by Hamilton Standard Project Engineering.

4.1.2 Vendee shall be Hamilton Standard Quality Control.

4.1.5.2 The vendee shall be Hamilton Standard Manufacturing Engineering.

4.1.6.1.1 Sampling - One panel shall be fabricated and tested for every 250 square feet of tape delivered to Hamilton Standard Receiving Inspection to the specification. For purposes of determining test frequency, all quantities of tape delivered to this specification to Hamilton Standard will be treated as cumulative quantities.

4.1.6.5.1 The vendee shall be Hamilton Standard Project Engineering.

4.1.6.5.2 The vendee shall be Hamilton Standard Materials Engineering.

3.2.13 -- and 4.1.6.5.3 The vendee shall be Hamilton Standard Project Engineering and Materials Engineering. Approval shall consist of countersigning Operation Sheets by the Vendee.

4.3 The Vendee shall be Hamilton Standard Quality Control.

The certified report shall be submitted in duplicate as an attachment to the shipping papers. The report shall include the following as part of the certification:

- a. longitudinal tensile strength of specimens #1 and #3
- b. modulus for specimen #3
- c. Transverse tensile strength of specimens #4 & #7
- d. modulus for specimen #7
- e. panel thickness measurements, as specified in 4.1.6.8.2
- f. chemical composition, as specified in 4.2
- g. tape identification number, as specified in 5.3.1
- h. filament diameter and calculated filament volume percent, as specified in 5.3.1.
- i. powder mesh size prior to spraying as specified in 4.2